Open University Geological Society Journal

Volume 29 Number 2 Symposium Edition 2008

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ISSN 0143-9472
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OUGS Journal **29** (2) Symposium Edition 2008, printed by Hobbs the Printers Ltd, Totton, Hampshire

Open University Geological Society Journal
Symposium Edition 2008

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Cover illustrations: Thin sections of several different habits of barite (photographs by Jane Clarke).

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Editorial

Dear OUGS Members,

Symposium papers take a great deal of time to transcribe or collect from the speakers/authors, indeed for the authors themselves to write, and then for the Journal *Editor to edit, compile and lay out the papers for publication.*

Thank you for your patience.

We held a successful and very interesting OUGS Symposium on the History of Geology at the Royal Holloway, Egham, beginning with a keynote lecture by Dr Allan Chapman about one of the founders of British geology, William Buckland, and finishing with what seems an appropriate, and basic, topic to earth science studies — geochronology — by Patrick Wyse Jackson. Between these two we were treated to a splendid array of topics and developments in the earth sciences, from the foundation of the Geological Society of London, through 'military' geology, the crucial role of women in the development of British geology, early palaeobotany, a taste of extraterrestrial geology in the study of meteorites, early advances in the understanding of hydrology, understanding the formation and structure of glaciers, conflict over the nature of the Ice Age in Britain, the development of data display in the geological sciences, the development of geological conservation in the UK, the establishment of the British Geological Survey, and in the midst of these, a summary of the career of our OUGS founder, the late Professor Ian Gass, Head of the Open University Earth Sciences Department.

*Dr Sandy Smith of the Open University Earth Sciences Department, current OUGS President and herself a former colleague of Professor Gass, summed up the series of lectures, including a few anecdotes of her own (*see Smith, this volume, page 98*).*

Many people put in many months of work to organise this symposium and it is only fitting that we should thank them again in print. Sue Vernon was Chair of the Symposium Committee, and the committee members were Sally Munnings, Maureen Lewis, Jo Lakeland, Eddie Yeadon, Nicole Gay and Jenny Parry.

We have the ever dynamic Di Smith to thank for pursuading and organising the line-up of speakers.

As is OUGS current practice, the Symposium lectures were recorded on cassettes and, if the speakers wished, we transcribe these recordings for them to help them write and prepare their papers for publication in the OUGS Journal. *The papers written by the speakers are here presented with their selections of illustrations to accompany them. Unfortunately, one speaker was unable to complete a paper, but we here publish an abstract, which contains the salient points of the lecture.*

As OUGS Journal *Editor I would like to thank personally the five people who worked hard to transcribe the taped recordings of the talks for me: Tracy Atkinson, Sandy Colville-Stewart, Anne Forrest, Anne Morton and Sally Munnings.*

Lastly, let us thank the speakers and authors of these papers. It is with great pleasure that I wish you 'good reading'.

— David M. Jones, OUGS Journal Editor

Erratum

OUGS Journal ***29*** *(1), 'Langkasuka ...', by Carol Hagan, page 28:*

The paragraph following the stratigraphy table lists locations on the map (Fig. 1, on the same page) as (1), (2), (3), and (4). These should have been A, B, C, D, respectively. The Editor would like to apologise to the author and to readers for this error.

Editor's notes to contributors

Following are guidelines for the submission of articles to the *OUGS Journal*. The principal theme encompassed within these guidelines is 'please keep it simple'. Let your editor do his job and please do not try to simulate, emulate or reproduce the page layout of the *Journal*. I have dedicated page-layout software (QuarkXPress) to do this and any special formatting, special characters and embedded illustrations that you include in a word-processing document can be lost (at best) or seriously confuse and crash (at worst) my iMac or the QuarkXPress software when I import it into the layout.

If your article contains special characters (such as mathematical symbols), please draw these to my attention (I will probably spot them anyway) so that I can import them properly with the glyphs menu in QuarkXPress.

Here are the basic guidelines. I will contact you about any queries that arise when I read your article. I will send you an edited version, showing you any changes that I have made and raising any queries or requesting any missing information.

Guidelines for *OUGS Journal* articles

As *OUGS Journa*l Editor I do not want the publication of your paper to be more work than is necessary for you (or for me!). Your paper need not be more than about 1,500 to 4,000 words in general, but I leave the length up to you to suit the material.

Regarding papers from the presenters of lectures at the OUGS Symposium, all OUGS members are grateful to you for presenting a talk at the OUGS Annual Symposium, and for agreeing to submit a version of your talk for publication in the *Journal*. The purpose of this is to make your information available to OUGS members and others who could not attend the symposium. As OU students and OUGS members we enjoy hearing and learning the information these symposia bring to us.

All that is necessary is the following:

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• Each illustration, chart, graph, map or other illustration as a separate digital file in high resolution: 350dpi minimum for colour or half-tone images; 1400dpi for line illustrations. Tables composed in Word or Excel are fine, as they are just text. A rough guide to the number of figures in an article is 5 to 10. Obviously as a symposium presentation speaker you might have shown numerous slides, so please use your best judgement on the number to include with the paper to be published — again usually 5 to 10 is a rough guide. *Please note that figures are normally printed in greyscale in the* OUGS Journal*, except Moyra Eldridge Photographic Competition winners.*

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That really is it! The editing and page layout are my job, so let me do it for you. I will communicate with you as necessary as I do this, with queries or difficulties with any formats, special symbols, characters, etc, as is the task of any editor.

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William Buckland and the foundation of English geology

Dr Allan Chapman (Wadham College, Oxford)

[Author's note: The author asks the reader to note that this paper is taken, mainly verbatim, from a recording of a lecture delivered extempore, and therefore has a different style of expression from that of a deliberately written text. He has tried to make some modifications to the spoken word, but sheer pressure of business has made it impossible to do the full-scale reworking that he would have liked. So he begs that the reader will forgive any errors or inconsistencies. But he hopes that he conveys something of the fascination William Buckland and his contemporaries of nearly 200 years ago had with the then infant science of geology, and of the remarkable contributions that they made.]

Introduction

I am speaking as a historian of science, and particularly one whose work has been largely in the history of astronomy and the physical sciences. But I've* always had a fascination with what has often been called the Oxford school of geology, which, of course, is William Buckland and his friends, in the early part of the 19th century. People often get the impression that Oxford science didn't exist until modern times.

There was of course the enormous period of activity with Hooke and Halley in the 17th century, but people often forget that between about 1795 and about 1850 Oxford hosted one of the greatest schools of geology and mineralogy in Europe, and the figure of course who really shot to prominence here after 1813 was the Reverend Dr William Buckland, Regius Reader in Geology and Mineralogy and Canon of Christ Church.

[Editor's note: contractions are normally expanded in formal articles, but so as not to disrupt the flow and dynasmism of Dr Chapman's talk, I have retained them throughout.]*

The background

But first of all, before looking at Buckland and at Buckland's world, I want to go back a bit. I want to say something about where coherent geological ideas came from. People often have the impression, which is perpetuated by certain popularisers, that everybody believed that the Earth was created in 4004 BC, that through a single act of Creation you had the dawning of the Genesis story, the Flood of Noah, human history from Flood to present times, and then on the 29th November 1859 *The Origin of Species* was published and the world went screaming mad. That is a popular myth. I don't want to name the names of people who encourage that myth, but it is indeed an utter piece of mythology.

This does not conform to our understanding of the earth, the earth sciences, or even life on earth for that matter. William Buckland had been in his grave in Islip Churchyard three years when *The Origin of Species* was published, and he had been a leading figure who had taken it as axiomatic that the earth was immensely old. They had no coherent chronometers to say how many millions of years, but vastly old. Also, he realised that life, pre-human life, had been through numerous different organisational forms, and that great developmental histories appeared in what was called the fossil record by the late Georgians and the early Victorians.

But even Buckland himself wasn't the first to think this way. You had people like Abraham Gottlob Werner of Freiburg, Germany, and James Hutton in Edinburgh in the late 1790s, who had also been actively considering where the earth had come from and how ancient it was. Werner thought it was formed by water, multiple great deluges of which the Flood of Noah just happened to be the last, while Hutton thought violent volcanic activity was the geological agent, and even suggested that Arthur's Seat in Edinburgh was the plug of an ancient volcano and that the whole of the base of modern southeastern Scotland had once been a gigantic ash cone, suggesting vast aeons of time.

Hooke and the age of the earth

Even before that it had been recognised that fossils corresponded to some kind of living creatures, and Robert Hooke, one of my biographical victims, on whom I have done a great deal of research, in 1664 gave the first of what were called his 32 'Earthquake Discourses' to the newly-founded Royal Society. The 29-year-old Hooke was a native of the Isle of Wight. He had been struck by the extraordinary and exotic geology of that island, and asked what parallels the island had to Portland and the Dorset and Hampshire coasts. Why did he find fossils at Hurst Castle on the English mainland, aquatic fossils 60 feet above high water mark, and how had they got there? Hooke gives the following theory of the origin of the earth in the early 1660s to 1770s. The earth, he says, was immensely old, and that at one time the Isle of Wight, England, Europe, all of this part of the world's surface, in fact, once formed the bed of a tropical ocean. The reason why you found giant ammonite shells in England is because, as he said, things grow to their greatest extent in the tropics. So therefore these giant ammonites probably were once in tropical seas, and because of a theory he developed called 'the wandering poles' (where everywhere on the face of the earth becomes everywhere else given enough time), land rises, land falls, erosion happens, and so on. You have a sort of actualist process going on. He developed these ideas even further and, indeed, you may say "I'll bet he got into hot water for saying that, didn't he?' Well, actually, one of his closest friends was Dr John Wilkins, one of his former Oxford tutors, at the time Bishop of Chester. His old mathematics tutor at Oxford was a close friend of his too — Seth Ward, the Bishop of Salisbury — and another of his great chums at this time is the Reverend Dr John Tillotson who, in 1691, 20-odd years later, when Tillotson is Archbishop of Canterbury, gave Robert Hooke a Doctorate in Medicine from Lambeth. That's a curious form of disapproval, isn't it?

So to have the idea that talk of an old earth and things of this sort would immediately have produced shock-horror effects does not correspond with reality. Biblical interpretations were much more liberal in terms of ages, aeons and so on, and, in fact Edmond Halley, a protégé of Hooke's in the 1690s, even suggests something astonishingly modern. Not only was it accepted as normal that the earth has had many re-workings in its history, and land and sea and relationships had changed, but also, says Halley, the earth in the past has been hit by comets. They knew nothing about asteroids in 1694, but comets, of course, in the wake of his great friend Newton's work, *Principia Mathematica*, were well known.

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One major section of *Principia* is about comets, and Halley was fascinated by what would happen if these objects, some of which were believed to be the size of the moon, hit the earth. Well, you would have some fundamental rearrangement of the earth's surface, wouldn't you?

Now why, says Halley, are certain great lakes on the earth's surface sweet and the oceans are salty? He particularly mentions Lake Titicaca in Peru and the Caspian Sea. Why are these vast bodies of water sweet and drinkable? Because, he suggests, at some stage in the past, long before there were humans, comets hit the earth. They then bounced off into space, leaving a great rip in the earth's surface, which slowly filled with water, and these rivers haven't yet flowed for long enough to get as salty as the oceans. Now these are big, big time scales — and are being discussed as early as 1694.

Hooke also asked the question — this is before we knew anything of the Gulf Stream — why is Hudson Bay vastly colder than Great Britain? They are roughly the same latitude; Hudson Bay is at something like Newcastle upon Tyne. He suggests that at some remote period in the history of the earth, Britain would once have been the equivalent of, let us say, North Africa or the equator. Hudson Bay could once have been the North Pole. Bang — a comet hits, knocks us slightly over in our orbit, and Hudson Bay and northern Canada move south and haven't really thawed out yet!

Now this is thinking over vast periods of time. Hooke also suggests that fossils were once living creatures. Hooke took fossils in the 1660s, particularly ammonites, carefully sawed them laterally into two halves, and found complex anatomical structures inside them. He even cut up other fossils as well, particularly ones he found on the Isle of Portland, and so came to the conclusion that fossils had once been living creatures. Yet, there is no known equivalent for them on the earth today. They are not mentioned in Genesis: where, therefore, do they come from? Well, in the late 17th century and in the early part of the 18th, theologians and scientists — and of course many of these men are learned in theology as well as in science — are examining *Genesis* carefully, and they are suggesting this: if you take *Genesis* 1.1, "In the beginning God created the heaven and the earth", that is the original creation of the World from nothingness as far back as you like. Verse 2 "And the earth was without form and void; and darkness was upon the face of the deep. And the Spirit of God moved upon the face of the waters." That is the beginning of the Biblical history. Between these two, you could insert as vast a period as you liked, and you could have a complex terrestrial geology and, of course, while this is thought to fit, reading carefully through the *Genesis* story you find, for instance, that trees were created before the sun. Now you know you can't have trees without the sun. Does this mean that the sun was vastly ancient, and that there had been a catastrophe that is mentioned as the old chaos in the *Genesis* story, the mess out of which the present world was formed? But actually, it is suggested, the clearing of the clouds and the sun begins to break through again. Because, of course, what these theologians were arguing, was this: the purpose of the Bible is to teach us a moral relationship with God. It is not to teach us science. Therefore the *Genesis* story is a moral history, the history of the Jews and our relationship with God. It is not about fossils, trilobites, ammonites, anything like that, all of them were gone long before we appeared.

Now when you look at history and biblical interpretation, you create an immense amount of opportunity, and this is essential for the development of the geological sciences. Why you do not get all of the legendary persecution we are told about? For instance, I defy anybody to find any English scientist who got into trouble for talking about the vast antiquity of the earth, and by scientists I mean at the top level — FRSs, not to mention the fact that there were always a very hefty sprinkling of clergymen and even bishops in the Fellowship of the Royal Society. However, one might argue that the Revd Dr William Whiston was ejected from his Cambridge mathematical professorship in 1710 for his beliefs, as indeed he was. But Whiston was expelled because of his denial that Jesus Christ was co-eternal with God the Father, which was a doctrinal, theological heresy, and not a scientific one. And while losing his job, he was never imprisoned or otherwise persecuted. The issue was not what modern fundamentalists suggest that it was, and certainly not the history that people like Richard Dawkins like to see in the past. It was a much more complex one.

By the middle of the 18th century, therefore, you have a generally accepted belief, among many people, that the world was very old. But whereas 6,000 years was believed to be the history of man or the animals we know today, on the other hand, minerals, fossils, plants — the increasing knowledge of things like the coal measures in the Industrial Revolution — was presenting tons and tons of new data. Now, in learned circles, this was not a thing of horror at all.

World exploration and new data

By the end of the 18th century there had been a great deal of global exploration, especially Captain Cook's voyages in the Pacific, the discovery of Australia, and things of this sort, and you discover there is simply far more data out there than was ever imagined before.

Volcanoes fascinated these people. They thought at that time that volcanoes were the natural creators of change on the earth's surface. Darwin, on the voyage of the Beagle in South America, sees a violent earthquake. He, of course, is clicking in to the way of thinking of the formation of oceans and continents. There was heated discussion about, for instance, why volcanoes occur where they do. Why, for instance, as Hutton says, have the Highlands of Scotland once been a blazing inferno of volcanoes, but nowadays, effectively, by the 1790s, were becoming a romantic tourist trap where people of Jane Austen's generation would go for the sublime and the beautiful and the glory of the mountains?

William Buckland

We now get to William Buckland, our subject for tonight. *[Editor's note: Dr Chapman's talk was given after the opening of the 2008 OUGS Symposium, on Friday evening, 8 August.]* Now let's say something first of all about the man's origins. I think it is always important to look at where somebody has come from. He was born at Axminster in 1784. He is the son of a well-beneficed clergyman. The Bucklands were old Devonshire gentry, clergy, comfortably off. From his youth he had ridden, would have known how to chase a fox, knew how to handle a fowling piece, all the things a young gentleman did in this period. His father, who was Rector of the parish of Templeton and Trusham, near Tiverton, Devon, was also keen on natural history, a great admirer of the recently deceased Captain Cook. In fact, this interest comes from his also living in a place where geology could hardly be missed. Indeed, Buckland's birthplace, Axminster, is near Lyme Regis, one of the most geologically rich areas of

Britain. Whenever you have a violent winter storm, part of the cliff would often come down, resulting in fossils on the beach. This is the period that fossil collecting gets going. This is when you had people such as Jane Austen coming to places like Lyme Regis — places where people would walk along the beach and pick up curious, figured stones after a storm. People across cultured society are getting interested in geology and the nature of the rocks and the vast aeons of time they seem to suggest.

Buckland therefore grows up as a young hunting, shooting, geologising, natural history Devonshire country gentleman, aimed for the Church, like his father. He is sent up to Blundells School, then Winchester College, before going to Corpus Christi College, Oxford; and Buckland always had a big, sort of larger-than-life aura. He had a tremendous, mad sense of humour, immense, irrepressible energy, formidable intellectual power and a gift for making friends.

Buckland at Oxford

Now, what was Oxford like in about 1803 when Buckland comes up as an undergraduate? Well, there is a popular impression that it's totally asleep, it's dormant. I don't think this has ever been the case, for the more you look at Oxford in the 18th century, the more astonishing it is. It is far more dynamic than you think. For instance, it has the finest astronomical observatory in Europe, the Radcliffe Observatory, begun in 1771, which was really used. But also mineralogy and medicine were of some interest, and the Regius Professor of Medicine, John Kidd, actually delivered lectures not only with bodies, and sometimes a *papier mâché* model of a body because he could not get a real one, but also on comparative anatomy and how a human was related to a monkey or a pig or even a thistle. There was nothing new in this, and it had been done for several centuries, but, in fact, the idea that there was a close connection between human anatomy, mineralogy, fossils, and teaching this in the university was a very new one.

On the other hand, Buckland would never have attended anything scientific for his degree. In those days if you went up to Oxford or Cambridge, your curriculum consisted essentially of two subjects, one the arts and the other, mathematics. The arts would include the whole of classical literature, theology, civil law, philosophy and so on. In other words, the discipline of absorbing culture and learning. A thorough understanding of Protestant theology, and a good bit of English civil law, because most graduates would end up on the magistrates' bench in the future and it was useful to know something about the English legal system, the constitution and things of this sort. Now for mathematics, perhaps, if you were really clever, bits of Newton, bits of Kepler, mathematical physics. What, of course, mathematics did for you was to cultivate the art of logical thinking. So therefore, you received training in the arts and philosophy, and training in mathematics, computation and calculation.

On the other hand you learned no geography, no geology, no engineering or chemistry or anything like that. Yet, for a long time, and certainly for 150 years, when Buckland had come up, there had been a number of professorships in the university that were there especially for delivering lectures in specific sciences: medicine, natural philosophy, what we would now call physics and chemistry since 1683, and mineralogy and geology, just established. There was also the Savilian Professor of Botany — the Botanical Gardens of Oxford are one of the oldest in Europe, established in 1619, with another professor in charge of them, so that you could learn botany. Now, who would go to these lectures? Well, in a way, the way in which people related to the sciences in Oxford in Buckland's younger days, was pretty well exactly like people feel today. In other words, you have occupations that you pursue, or retirement, or whatever, yet you have a passionate interest in an intellectual subject. In your case, of course, geology. You choose to join a geological society and attend periodic geological lectures. It was exactly the same at Oxford, and Cambridge, at this time. What would happen, you may have read your Horace or your Virgil or St Paul's *Epistles*, or Euclid's *Elements of Geometry*, but you know there is a jolly good lecture on experimental chemistry currently running in the Museum, and then extraordinary ones on fossils and minerals, so let's go along. And so you get the young gentlemen going along to learn: they're never going to get examined in the subject, there is never going to be a formal grilling, but they are going to learn a heck of a lot. Now that's an aspect of Oxford and of Cambridge education that was fluid but was often completely missed, and what you often get is a closed world of no science.

It's rather like the Open University, you do it because you want to do it, and there were always large numbers of takers for these lectures, depending, very often, on the personality of the lecturers and things of this sort. For instance, Thomas Hornsby, the founder of the Radcliffe Observatory, was Savilian Professor of Astronomy. He taught astronomy to packed audiences of young men who would never need to do it for examination. He taught them how to use instruments, how to use electrical machines, things that today would be banished from virtually any school and probably certain universities, how, for instance, to ignite gunpowder with sparks from a shotting machine and things like that.

Hornsby owned £375-worth of private apparatus that he used for his lectures. £375 in those days was a sum of money that a successful barrister would earn from his practice in a year. Now you can get some idea of the quality of the kit that these men had — invariably their own. Not of course paid for by any kind of university body or anything like that — their own. Because, if you had the latest contraption, the latest device, you would get more students and, of course, you could get a few more guineas, because you could always charge for the people coming to the lectures. So this is how the system worked. There was actually a lot of science, but you picked and chose, and you decided what you wanted to do.

Buckland entered this world. In some ways he entered on the coat tails of John Kidd. He is fascinated by anatomy, medicine, and so on. But you may wonder what good all this stuff is.

I would argue that that education survived for so long for a very good reason — it worked; and the value of an education depended intimately on what the person receiving it was going to do with it once they had got it.

Now let's take the average sort of profile of a gentleman who would be at Oxford or Cambridge in those days. There would be scholarship boys on the foundations of their colleges, future clergymen of the Church of England and other professionals. You might be a vicar in Cornwall, you might be from a Northumberland mining community, there would be people dying in the mine, so you go to the vicar. "What's wrong?" "Oh dear, that's marsh gas, you get that in deep mines." And this would happen. As I said, you must have clergy educated in medicine, who have no medical qualifications, but who have done some medicine at university and read up medical books. For example, Sydney

Smith, the famous Georgian wit, in about 1812 was vicar of the large parish of Foston, North Yorkshire, when a violent fever epidemic broke out. There were no doctors within miles and most of his parishioners were too poor to afford a doctor's fees, so Smith simply sent off to London for the latest medical books on fevers, got on with it, and from this and from what he remembered from New College, Oxford, 30 years before, he knuckled down, and actually saved lives in the parish. Now, can you imagine the local vicar coming in to stem a fever epidemic?

Now the clergy are one thing. There are others too who are obvious, such as, let's say, those who become doctors, who work in the healing arts, and country gentlemen who enter Parliament. Well, of course, if they are already trained in natural philosophy, chemistry, astronomy, this is jolly handy. Likewise, too, if you go even higher up and you become a judge or a bishop, in the Lords, you have the capability of making reasoned judgements in debates from what you know. Let's say you enter the diplomatic service or become a colonial administrator; it is jolly useful to know the nature of minerals, smelly gasses that come out of the earth, tidal waves, all of these sorts of things. So I would argue that this kind of education was very useful for these people and the jobs they were going to afterwards — all of them would be basically going into leadership positions in that society, from country vicars on one hand, to leading members of the House of Lords or Governor Generals of India on the other. So, in that respect, scientific culture ran deep in their understanding.

Buckland was exactly of this mould. Now, he does very well as a young man. He takes his examinations in classics and in mathematics, passes everything well. All of the examinations, I may say, were oral, or '*viva voce*'. You would know the areas you were going to be examined on — let's say you were going to be examined on Horace's *Odes* or St Paul's *Epistle to the Thessalonians* or something like that, and you would know you were going to get a grilling from a panel of elderly gentlemen who had been through the same thing themselves. And your quickness of wit was crucial. People sometimes think this examination system was easy; it wasn't. Whereas today, what is asked for in the exam is the ability to work for three hours on a piece of paper and work out something very elaborate and write it down, their system was different. They worked on the idea that most of their members would go into some kind of public life, the Church, Parliament, the law — talking on their feet; so they felt that they should be examined on their feet. "Mr So and So, such and such a person said to Ajax at the siege of Troy … What does this mean and can you finish the quotation?" That is what got you your best cases in the courts; it got you your preferment in the Church, acclaim in Parliament, and so on. That kind of mental edge was essential. So they were aiming for men who were quick thinkers, sharp, widely learned and able to 'throw back'.

This is why this period is spoken of as the golden age of Parliamentary oratory. William Pitt, Charles James Fox — all came from this very system. They were literally chucking words at each other in quick debates. They perfected these arts in Fox's case at Oxford, in Pitt's case at Cambridge, but with almost the same intellectual skills.

Which, therefore, is why I say that Buckland received a jolly good education, which was focussed on the kind of work he was going to do — as a clergyman and as a geologist. Now, as a bright, very personable, friendly young lad, he is collecting fossils all over the place. And, of course, as you surely know, the Oxford area is rich in fossils. You have all sorts of places where they can be found: you have various quarries, Shotover and places like that, and because there is stone constantly being dug out for work on College buildings, you could go out to Shotover or somewhere like that on your horse in an afternoon, be in the quarry with the workmen and identify the strata. Buckland would be doing this when he was about 19 or 20. So he was taking pals out with him. He acquired a good knowledge of field geology of his own. And when he was back in Devon in the vacation he was only going to interpret the cliffs and the coves around Ashburton at the bottom of Devon. Now this is where he's coming from. His rooms in Corpus Christi begin to burst with bones, fossils, trilobites and ammonites, and he is becoming something of a phenomenon in his own right. Buckland, of course, often used to invite lots of people to dinner and drinks parties, and at a drinks party in 1810 with three bottles of port per man, amid the bones and all the rest of it, in the centre I believe he even articulated an ichthyosaurus and used it as a candelabra by putting candles on its vertebrae. Now that's geology with humour!

Continental connections

Now, why am I telling you all of this? At this time, 1800/1810, perhaps the leading geologists in Europe were not quite geologists, but comparative anatomists. For example, there is Georges Cuvier in Paris: Cuvier is an anatomist, not a geologist, but he is fascinated by what he sees as the laws of organic development and the laws of organic synchronism or congruity. For instance, certain types of bones are only found in certain types of animals. For instance, let us say you take an animal that has long leg bones, joints that are very flexible, and a fairly light body, which you can determine from the shape of its rib cage, a long whippy tail, claws and pretty nasty-looking teeth. You know that creature doesn't eat grass!

Ditto for, let's say, the hippo, a short, fat, slow-moving creature. He made that incredible realisation, that organic structure — anatomical structure — governs the lifestyle of a creature. And when, therefore, in the Paris shales, in the beds of the Seine at low water and elsewhere, when he found lots and lots of bones on sandbanks, he realised that these creatures were not only before the *Genesis* creation, or more correctly before the period before *Genesis*, in the gap between, but that they are not like any living creatures today. They are earlier forms. Yet, you can put them together, if you know your anatomy, if you know your modern comparative anatomy and zoology, you can put them together by bone structure and so on. And he causes a sensation in Paris, in about 1810, by articulating these extraordinary creatures. It was widely publicised.

Of course, England is at war with France at this period. We are in a ding-dong war of survival against Bonaparte. On the other hand, there is a remarkable exchange between the French *philosophes* and their British counterparts. So French journals are read in England, British journals get to Parisian libraries, and so Cuvier's work is fully known in Oxford, Cambridge, London, Edinburgh, and other centres of learning. Buckland is fascinated by Cuvier's methods. When, in fact, the French wars are over after Waterloo, he goes to France and meets Cuvier and has something like tutorials and teaching sessions with Cuvier.

Buckland in 1813, just before the end of the French wars, is appointed Reader in Mineralogy. In this post he used to lecture to students on the nature of minerals and the function and structures

of them, how they were thought to form, how natural minerals were perhaps related to artificial minerals, such as graded salt crystals in a pot and things of this sort. And because he is such a brilliant lecturer, a brilliant demonstrator, he starts, from the word go, getting capacity audiences. Buckland therefore becomes, as a young man in his early 30s, a famous mineralogical lecturer in Oxford. He also attempted to articulate skeletons, including, of course, as I have mentioned, the ichthyosaurus that he used as a candelabra in his rooms in Corpus Christi. And then in 1818, the Prince Regent, shortly to become George IV in 1820, gives him the title of Regius Reader in Geology. So, in other words, he now holds a Geological Chair appointed by the Crown. Now this is entirely in keeping with all the posts and the Professorships in Christ Church, the College which he later moves into as Canon in 1825, because there, the Regius Professor of Greek, the Regius Professor of Ecclesiastical History, the Regius Professor of Divinity, all of these are Crown appointments. So Buckland has a Crown appointment, a scientific Crown appointment, which now is placed in Christ Church.

He is, of course, ordained in Holy Orders, he is the Revd Dr Buckland, and with this new post goes a Canonry of Christ Church. So he holds a leading theological chair and a leading scientific chair at one and the same time. Now in this way, Buckland becomes very influential. He does a number of key things, which, of course, we would only regard as normal in something like a geological session — field trips. Not just showing his students the minerals and bones that he has in abundance, but taking them out to show them the wild landscape. Taking them to Shotover, then taking them to Sonning shortly after they had started to dig it up, to see the wonderful things that came out of the landscape. Now the one thing they had not yet understood precisely was why certain types of strata seemed to have certain types of organisms in them.

William Smith

Now this is to be made known by a man called William Smith, and it is William Smith — who is a canal surveyor, a working surveyor, not a scientist — who really makes this breakthrough. And it shows what an open house geology actually was in this period; people from very diverse backgrounds could make original contributions. Smith, of course, makes this discovery as a working canal surveyor, noticing how the synclines and the anticlines of the English landscape, when he was digging a trench for a canal, could predict what kind of fossils he would find as the hillside went down and came up again. He realised that these related to developmental periods in earth history, and in 1815 published a major map — the first ever geological map — the subject of a best-seller book a few years ago, entitled *The Map that Changed the World: the Tale of William Smith and the Birth of a Science* (Simon Winchester, 2001; London: Viking). And if you go to the Geological Society, London, in Burlington House, you see the great map there, hanging on the wall.

This is a product of Smith, a working surveyor, traipsing across Britain hundreds of times on horseback and noting what he sees — all those coloured contours, and what he sees in the landscape. The amazing thing is that he's right, that he put in a colossal amount of details, but the basic structure is right.

Buckland, his Cambridge counterpart the Revd Professor Adam Sedgwick, and most of the leading geologists of the day knew, or came to know, William Smith, and held him in much respect. And while Smith had financial problems, and even resided for a while in debtors' prison, he came to win great recognition, receiving the Wollaston Medal of the Geological Society, and then, in 1835, an honorary Doctorate of Laws from Trinity College, Dublin. Adam Sedgwick styled Smith 'the father of English geology'.

Now that is real meritocracy — Dr Smith. But Smith's keen realisation that fossils themselves were indicators of the antiquity of strata, and that you could use strata to mean fossils and fossils to mean strata — that becomes one of the greatest breakthroughs. And Buckland, because of his position in the geological establishment, was able to make this an intrinsic part of teaching in Oxford. The young gentlemen, therefore, who were to go off to their Cornish parishes or to become Governor Generals of India or to man His Majesty's men o' war on the oceans, leave Oxford knowing this. That is an important thing to bear in mind. Buckland, therefore, is a true educator, what you might call a populariser of science. He is not himself a great original discoverer, but the essential thing with Buckland is that he is an astonishingly gracious communicator, a great encourager of others and, because of his central position, had a way of getting through to the biggest possible audiences.

Caves, bones and floods

But then, Buckland would probably have regarded as his most important single discovery the one he made in 1821–22, at Kirkdale cave in northeast Britain. Workmen in 1821 were digging a hole in the ground at Kirkdale, up above Newcastle, and a workman lost his pick through a hole in the ground. They dug in and got the pick back, and it was found in a cave. But then looking around on the cave floor by lamplight, they found bones. Curious-looking bones, and it was very obvious that nobody had ever been in this cave before. It had been sealed in, a vast sealed-in cave. Buckland hears about it. How does Buckland hear about it? Like Buckland hears about everything! Pretty well every country clergyman in Britain knew about Billy Buckland, and if something interesting was dug up in his parish, there were letters sent to Christ Church.

Buckland hears about it, and is on the next mail coach to Newcastle. He turns up at Kirkdale. He calls on his pal, William Daniel Conybeare, another of his geological chums from Oxford, another clergyman, and they go to the cave. What are these bones? Hyena bones? But there are no hyenas in Yorkshire! There had never been known to be — so how far back do they go? And then he found as well, bones of other creatures, like wolves and bears. But all the hyena bones were intact, whereas the bones of the other creatures were cracked or bitten or gnawed. They had been food for the hyenas. This had been a hyena den, and the hyenas had dragged their prey in and eaten it in the quietness of their caves. Now, this was incredible.

Buckland now has a suggestion: Could they have been victims of the great Flood of Noah? He accepted that the Flood of Noah was a real historic event, not the only such event — there had been lots and lots of massive global shake-ups before that as the great catastrophes had lifted one epoch into the next to account for the strata. But could it be that one night, somewhere about 1,600 years after the *Genesis* Creation, the hyenas had dragged their supper in for a nice quiet evening at home, gnawing their bones, and the waters had come flooding in, sealed them up, and locked them in until they became fossilised, until 1821 when they had been found? Now this is tremendous, it is newsworthy, colossal; it is picked up by the press and, of course, Buckland's fascination with

caves seems to seal it, to bring it out. Does it now mean that you actually have proof of the Flood of Noah? Buckland, now, may say in 1821 that he believes that the Flood of Noah was an active geological agent, but by 1836 he had abandoned the idea, realising that the Flood was probably something local, perhaps in the Euphrates Valley area. It shows how rapidly discoveries are moving in this period. But the idea remains, however, that you might have had a flood that got to England and walled in the hyenas.

Then of course everybody starts writing to him about interesting caves in their parishes and things like that. He goes to Paviland, not far from Cardiff in South Wales, and there he finds a human skeleton in a cave and wonders exactly what it's doing there. Well, there was also a recent excavation of a Roman site, near Paviland, and the skeleton was believed to be female. He was asking, could this have been an ancient Briton connected to the camp of the Romans? Now, of course, we know that the skeleton was vastly older than the Romans. He goes to Torquay and examines Kents Cavern, which was in fact one of the most famous public caves in Britain. Father MacEnery, a Roman Catholic Priest at Torquay, had himself done major geological researches in Kents Cavern. Buckland works with him there. Caves have now become a major thing, they are sort of markers of the Great Flood and of previous floods, and are tremendous treasure-houses for bones. Usually mixed up, sloshed up bones, indicating that the creatures in those caves had met watery ends. This is the way in which Buckland's ideas are burgeoning in the 1820s and early 1830s.

What then leads him to abandon the idea of the Flood as a geological agent? Not, of course, as a Biblical agent, yet it happens that his Flood gets smaller and smaller, until it gets virtually limited to Mesopotamia. Because, as geological knowledge got greater and greater, he came to realise that there were also other causal agents in geology. He comes to realise, in the wake of Louis Agassiz, that ice is a major agent in forming northern Europe (*see Duffin, this volume, page 52*). Therefore the parallel roads of Glen Roy in Scotland and also the great U-shaped valleys of Scotland and the Lake District, traditionally thought to have been formed by vast tidal currents of water, by floods, he now knows are produced by ice. The moraines suddenly click, ice just like in Switzerland, and as ice gets bigger, the floods get less and less prominent and, by the time he writes his famous treatises on Geology in 1836, the *Bridgewater Treatises, Geology and Mineralogy considered with reference to natural Theology*, the Flood simply isn't there. It shows the flexibility of the man's intellect. Fifteen years before, every watery mess in a cave was a sign of the Flood. By 1836 the Flood had quietly receded to the Middle East as more and more data had grown up around him.

Buckland the communicator

Now Buckland, of course, was a tremendous communicator — he was a riveting and dramatic lecturer, a conductor of field trips, and he was in Oxford until 1845. Now in 1845 there was a railway running across southern Britain, Brunel's Great Western Railway and as, in the late 1830s, Irish labourers were digging the cutting at Sonning, Buckland realises that the slice through the English landscape is rich in fossils. Just like today, if you take the road from Oxford into London, the fast road that goes through the enormous Chiltern Gap, you see the fossil layers there. What does Buckland do? He starts taking trainloads of students to see Sonning and other cuttings. Now in those days, of course, trains were not as frequent and, with very low frequency, you could hire a train just like you can hire a bus today, let us say stopping at Sonning cutting. Buckland brings this power of the new technology to the expanding understanding of geology, by using it for field trips.

Buckland's geology is essentially cataclysmic. He called it catastrophist, and this is basically the model by which it happened. Any time there was any change of settled habitation on the earth, let's say the most primitive molluscs or trilobites or something like that, or higher creatures, God decided when they had had enough. A new order of creatures was necessary. So therefore God destroyed that particular orbit of life. And this may be by meteor or violent volcanic activity, or some other agent. And then, after the mess had settled down, God chose to repopulate the world with a higher form of creature. This was when God would bring in new orders of life, strata-breaks characterising each new creation, and eventually end up with large creatures, not very different from the ones that we know today, those that suffered immediately before the Genesis I, v. 2 narrative began. Then, bang, it is the last one, and then, "the Spirit moved on the face of the waters and God created the day and the night", and thence the Creation story. So, in other words, you have this vast punctuated history from far back, from the Creation to 4000 or so BC and a vast amount of geology in it: mineralogy, crystallography, the study of minerals, cataclysms, and so on. This is Buckland's geology.

Yet he had a number of brilliant pupils. Buckland, it might be said, was a tremendous figure, and indeed he becomes well known in very high places. Albert and Victoria thought he was wonderful. He is not only frequently invited to Buckingham Palace and to Windsor Castle, where the Royal Family enjoyed his company, but in 1845 he became Dean of Westminster — Dean of Westminster Abbey, probably along with the Deanery of Windsor, the two most senior posts in the Church of England close to the monarchy — though, of course, both of these are Chapels Royal, and hence, of course, the Queen or the King worshipped in these places. Only men of the most respected and Royalist kind would hold them. Buckland is appointed in 1845. He goes down a treat. The Queen, and especially the very intellectual Prince Consort, Albert, loved him, and his tours of Westminster Abbey were allegedly very famous for visiting dignitaries, ambassadors and people like that. He would point out the different parts of the Abbey and the different stones of which they were built. The ancient altar and carving from northern France, and how Hawksmoor had rebuilt the front towers from different forms of English limestone. He even had a bosun's chair rigged up at one stage so that he could conduct a detailed study of the exterior of the Abbey, fossil by fossil.

Buckland, of course, was a stickler for protocol and for dress, and he always wore for anything remotely formal his academic robes from Oxford. So, therefore, when he is taking, let's say, visiting ambassadors or heads of state around Westminster Abbey, he would meet them, doff his mortar board in the proper fashion, and take them through, but very often would go around with them with a long feather duster, 'tickling' various figures and late busts of the great and the famous as he was going along.

He was also a legend in the Abbey. The cat once fell down one of the great organ pipes and the problem was, how do you get pussy out of a vertical organ pipe? Buckland had the right idea: take a piece of string, tie a rich-smelling fish to the end of it, let it down into the organ pipe, and pussy would immediately grab

the fish and out you would pull her, safe and sound. That kind of practical but utterly zany intelligence, you find in William Buckland — which helps to explain why he was so appealing and why he was so very popular.

Murchison, Anning and Sedgwick

But I mentioned earlier on that he was a countryman. So many people in early geology were countrymen and, increasingly, countrywomen. I think geology also had a connection, not only to the Church, but to the army. You may wonder why. But here I want to say something briefly about Sir Roderick Murchison, the first proper Director of the Geological Survey as you all know him, for he was one of Buckland's pupils when at Oxford (*see Rose, this volume, page 10*). But where had he come from before he went to Oxford? The army. He had been put into the army, into a Yorkshire Regiment — he was a Yorkshire Baronet, and he served with great distinction. In 1808, when Sir John Moore covered the retreat from Corunna in which Moore himself was killed (one of the most famous deaths in British military history), it was said that the young ensign carried the flag — carried the Union Jack to safety away from the French, before the next attack against the French. He was an experienced soldier.

Murchison was a cavalry officer. Now you think of this, if you go somewhere like Spain, where he was serving as a young man, and you are fighting the French, and you have never been to Spain before, and you have got a couple of thousand hussars behind you and you are attacking the French three miles ahead and part of the strategy is to ride hell for leather at 35 miles an hour with your lances and your sabres at them, you learn one thing — to read the landscape! Where may they be hiding, what is the terrain like, what holes are in the ground, what will take a thousand horses and what won't.

He learns in the army to read the landscape and when he goes back to Yorkshire, after the end of the Napoleonic wars, he takes to fox hunting. Again, it is useful to know where to ride your horses so you don't break your neck. And while fox hunting he was fascinated by the subsoil and what was underneath it, and fossils and minerals, and he goes to Oxford for a course on geology with Buckland. He's captivated — soldier, country gentleman, geologist — for the rest of his life.

Now these are the routes by which people come; one other important person too, is Mary Anning. Mary Anning, the first proper female geologist, of Lyme Regis. She has obviously not come from the rich classes, she and her mother ran a sort of tourist knick-knack shop in Lyme Regis. People wanted to buy fossils to take home, for cabinets of curiosities were fashionable among the well-to-do. She became a skilled field geologist, one of the experts in South Devon geology. And in fact, it was down in the south, at the age of 39, that Buckland recognised her as one of the greatest geologists in southern England.

Now you see there is another thing that happens with geology — it has to be a leisurely discipline. There are no real professorships or a properly-paid chair. Yes, Buckland had a chair, his friend Sedgwick in Cambridge had a chair, but really these are not like modern chairs, where you have got this body of students, you have got these forms to fill in — no, nothing like that. You were there to be an inspiration rather than an academic bureaucrat, and you had all the free time in the world, and a Church of England Canonry would normally give you your real income, and this, by definition, meant that you were a gentleman of independence. This meant, therefore, that you could inspire rather than fill in forms, and this is why I think Buckland, and of course his great friend about whom I have said very little, Adam Sedgwick in Cambridge, were like a pair of pot dogs on a mantelpiece: charismatic, clever, humorous, hare-brained and brilliant.

Country gentlemen, students, ladies — this is also the romantic age. This is the time when you had Wordsworth writing about the beauties of light on Lake Windermere; this is the time when you had poets swooning over the sublimity of the Highlands at sunset. Geology fits that world perfectly. What do you do? You leave southern England early in summer, head north, well, we'll stay with our friends so and so at this castle, at this great country manor house, then we'll shoot here and we'll ride there and we'll geologise here and we'll collect botany over there. Geology fitted into that world. Jane Austen's world is the world of the early geologists. You think of Jane Austen's novels with geologists in them. That is exactly the world she lived in. And a little bit later, in Anthony Trollope's novels — exactly the same kind of people: an educated, cultured, leisured elite with good brains and great curiosity. This is the world in which Buckland lives and moves.

Sir Charles Lyell

Another person, to me, of great influence was Sir Charles Lyell — another man who goes and studies with Buckland on what you would call a sort of special course. He developed a different theory of the age of the world — the idea that things could change by gradual, slow, small changes. Not by cataclysms. Well, he does this by geologising in southern Italy and finding in particular Greek ruins, no more than 3,000 years old, a lot less than the age of the Mediterranean, and seeing that in a mere 3,000 years you could have had the Temple of Serapis at Palermo sinking under water, so could perhaps the whole of the world have been formed like that, by gradual changes, not by violent explosions, like Buckland's. He formed the school that is seen as a gradualist school, which the French call uniformitarian, not unitarian, uniformitarian geology, where the same forces of wind, erosion, pressure, rain, given long enough, will produce all the changes that you need to produce the world we have today. You may say, hang on though, what about living things? If you need breaks in the geological record to get from a lower form of life to a higher form of life, how did it happen here? Well, of course, it's not for nothing that Lyell is actually trained as a barrister. Because he thinks just like the lawyer he actually is. He puts forth this in his *Principles of Geology* Volume 2, in 1831, and I think he knows it's sticky and it's not easy to push too far, but he tries this one on: "When God made the entire earth, then he made pretty well every kind of living creature that would ever live", so the tyrannosaurus was contemporary with the domestic cat, effectively. Well, all creatures had their own part of the earth's surface, and because there is endless change by slow, slow changes within the earth, those creatures that were in atmospheres and environments where they were not adapted, such a swamp-dwellers, when their swamp dried up, they'd had it, they just died. And if all the big swamps dried up, then the creatures living in them all just simply become extinct. Cats, lions, and bears don't live in swamps, they can move, so when their environment changes, they can skedaddle to somewhere else.

So you have a sort of winnowing of the animal population so that, gradually, fewer and fewer species are around. What there are left are perfectly adapted to their environment. Very good idea.

Now this becomes, as it were, a great rival to Buckland's. Not really a great rival, because Buckland always had more eggs in his basket ultimately than Lyell, at least until the time of Darwin in 1860 to 1870.

The geologists' world

But what you have here is a fascinating world. What so captured my imagination among Victorian geologists, and late Georgian geologists, is the world in which they lived. A highly friendly, affable world: it's social, it's one with balls and dances, with a concept of what is a proper education for a young gentleman, and of what you are going to do with that education in later life. Because, too, English science did not come out of the universities, but rather came out of private interests. It was open to women. You didn't have serious, active women scientists in France or in Germany, where you needed a PhD to be taken seriously. You met people like, well, Mary Somerville, the great mathematician, Ada Lovelace, Mary Anning: all were *persona grata* in British science, because of course there, if you'd got it, you were taken seriously at the soirée, the discussion, the philosophical meeting. No government minister was going to exclude you from scientific work because you were a woman, and could not have a degree. We had no ministers for education or science in those days; education looked after itself. No matter, of course, what most people get up to today, the clear fact that then there was no such thing indicates a different approach to higher education. One thing it did, though, is create a very wide and a very inclusive world, and inclusive right down to working people. Mary Anning was a working woman with a shop to run in Lyme Regis. And you come across numerous cases of coal miners, country workmen, stewards on gentlemen's estates, stone masons. Hugh Miller, the great Victorian geologist, was himself a working Scottish stone mason who moved into geology, who had something to offer and was taken seriously, and this is, I think, why geology is an immensely wide and respected science. Even with the founding of the earliest amateur Geological Society.

This, therefore, is the world of William Buckland.

But I want just to end with one of the many Buckland stories, which is almost certainly true because there is no reason why it shouldn't be, and it comes from the time when Buckland was in Christ Church, Regius Reader in Geology, and he had a visit from one of the many country clergymen who came to see him because of the interesting things that had been dug up in their parishes. Now, by this time, around December 1830, Buckland was married and had a little son called Francis (born 1826), later to become himself a spectacular scientific and medical eccentric of the middle and late Victorian age, Dr Frank Buckland. As Frank Buckland's biographer subsequently related, 'About this time a clergyman travelled from Devonshire to Oxford, to bring Dr Buckland some "very curious fossils". When he produced his treasures, Dr Buckland called to his son, who was playing in the room. "Frankie, what are these?" "They are the vertebrae of an ichthyosaurus", lisped the child, who could not yet speak plain. The dumbfounded clergyman returned home crestfallen' (*Life of Frank Buckland*, by his brother-in-law George C. Bompas (Thomas Nelson & Sons, London, Edinburgh, Dublin, New York; undated, *c.* 1905), page 13).

The famous bust of William Buckland (1784–1856) in Oxford University Museum:

WILLIAM BUCKLAND. D.D. F.R.S.
READER IN MINERALOGY 1813–5.
AND IN GEOLOGY 1818–56.

James Parkinson: medicine, the founding of the Geological Society and a little light treason

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Editor's note: Unfortunately, Dr Lewis was not able to complete a paper on her talk at the OUGS 2008 Symposium. Here is the abstract of her talk, as published in the Open University Geological Society Symposium 2008 programme (with some modifications by Dr Lewis, and slight editing), 'The History of Geology'. Dr Lewis' talk was recorded at the Symposium.

At the age of 16, James Parkinson (1755–1824) was apprenticed to his father, then the apothecary surgeon in Hoxton, a village on the outskirts of London, to learn the art and mystery of being an apothecary. When his father died, James was left to manage the practice single-handedly. During the 1790s, he became heavily involved in radical politics, joining several societies founded to campaign for the reform of parliament. Despite William Pitt the Younger (1759–1806) having been elected Prime Minister in 1783 on a promise of social reform, the common man (and woman) still did not have a vote. Under the pseudonym of 'Old Hubert', Parkinson wrote many political pamphlets that ridiculed and harangued a corrupt and incompetent government for the soaring cost of food and high taxes, incurred as a result of the war with France.

Convinced that Britain was about to follow the French Revolution, the government became increasingly concerned about these radical societies' activities and arrested the leaders on a charge of high treason. On learning of the arrests, Parkinson immediately offered to testify before the Privy Council on behalf of his friends, hoping to show them the ludicrous nature of the charges. In the prevailing political climate, he must have realised that he ran a serious risk of being implicated in the plot, and that he could be putting his life in real danger. Earlier that year, five men in Scotland had been transported to Australia, having been found guilty of the lesser charge of sedition.

Parkinson had an excellent knowledge of chemistry and recognised the importance of it to the medical practitioner. He even wrote a classic textbook on the subject. He also wrote many medical works aimed at the general public, to help them assess in times of sickness whether or not to call in the physician. With these same principles in mind of 'improving' the general public, Parkinson published his three-volume work on fossils: *Organic Remains of a Former World* (1804, 1808 and 1811). This masterpiece put palaeontology on the scientific map of Britain.

Having become interested in fossils as a young man, Parkinson had tried to find publications in English that would help him to understand their significance, but little was available at the time. Assuming that others must be having similar difficulties, he decided to write the definitive book himself. *Organic Remains* was aimed at a popular readership and written accordingly. Nevertheless, the work reveals a man fully conversant with contemporary geological ideas being propounded on the Continent, ideas that were, in general, in advance of those in Britain. In 1807, his expertise as the country's only 'fossilist' resulted in his becoming one of the 13 founders of the Geological Society of London.

In 1817 he published the work for which he is best remembered today and which resulted in the disease he identified bearing his name. His essay on the *Shaking Palsy*, now called Parkinson's disease, has deservedly become a medical classic, but it was for his work on natural history that the Royal College of Surgeons awarded him their first gold medal. Parkinson's achievements were also recognised by European geologists and he had several fossils named after him. However, his political radicalism barred him from becoming a Fellow of the Royal Society, despite his scientific achievements being far greater than many other elected Fellows.

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World wars: a catalyst for British geological innovation

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Abstract

The Geological Society of London was founded in 1807, effectively in the midst of a world war. The war's military imperatives stimulated British initiatives in topographical and, soon afterward, geological mapping, and created opportunities for geological teaching as part of a military education. Much later, the Great War of 1914–1918 saw the first British military geologists to be deployed in uniform to support battlefield operations. Faced with near-static trench warfare in France and Belgium, their innovations included development of a variety of groundwater prospect maps to guide well drilling, plus engineering geological maps to guide the excavation of protective 'dug-outs' for front-line troops. In contrast, the World War of 1939–1945 was a more mobile conflict. Military requirements stimulated British hydrogeological studies, notably further development of groundwater prospect maps within a wide range of geology-based 'terrain analysis' maps to guide the Allied landings in Normandy on D-Day, 6 June 1944, and campaigns across Europe and the Far East.

Introduction

British geological innovation was stimulated by three periods of warfare on a 'world' scale: the French Revolutionary and Napoleonic Wars of 1792–1815, the Great War of 1914–1918 and the Second World War of 1939–1945. This paper describes how programmes of British geological and geotechnical mapping especially were generated as a response to perceived military applications. It provides an introduction to aspects of applied geology, which have been described in articles dispersed across a wide range of literature, and is based largely on selected articles by the present author, in which primary data sources are documented more rigorously and comprehensively.

The French Revolutionary and Napoleonic Wars 1792–1815

The French Revolutionary and succeeding Napoleonic Wars, a series of intermittent conflicts that spanned most of the period 1792–1815, arguably constituted a world war – involving Great Britain from 1793. Within this 23-year period, hostilities spread across much of Europe, across the Mediterranean into Egypt and the Levant, across the Atlantic into the Caribbean and North America, and into areas of the Far East, notably India. Although not the first world war (for the Seven Years War of 1757–1764, between Great Britain and France and their allies, similarly involved conflict widespread in geographical scope), it is widely perceived as the first such war of modern intensity. It affected the careers of four of the 11 primary founders of the Geological Society of London present at its inaugural dinner on 13 November 1807 (Rose 2009a).

During this period of warfare a military commander took geologists, as such, on a military operation for the very first time: Napoleon Bonaparte, for the French invasion of Egypt in 1798 (Rose 2004a, 2005b, 2008). Victorious at the head of French troops in Italy in late 1797, early in 1798 Napoleon was placed at the head of an army forming to invade England. However, he quickly realized that his resources were inadequate for that task, and gained government approval for an invasion elsewhere: Egypt, to make France a power in the Levant, and to counterbalance growing British power in India. His force of 400 ships brought some 55,000 soldiers, sailors and marines to land near Alexandria on 1 July 1798 — ostensibly to liberate the Egyptian people from their Mameluke overlords, who ruled largely in defiance of their Ottoman Turk superiors. His army was accompanied by a Commission of Sciences and Arts: about 150 engineers and other specialists whose task was to examine every aspect of modern and ancient Egypt, so as to provide information that would enable the French to govern the country effectively.

The Commission included four members specifically as 'mineralogists' (i.e. geologists), to examine the natural resources of a land largely unknown to Europeans. Their leader was Déodat de Dolomieu (from whom the mineral dolomite has been named), who was a 'professor' (but without tenure of an established chair) at the School of Mines then being re-developed in Paris. He was accompanied by three of his recent graduates from the School: Louis Cordier (later to become one of the most distinguished of French 19th-century geologists, and from whom the metamorphic mineral cordierite is named), François-Michel de Rozière (later a chief mining engineer with the *Corps des Mines* in France, and briefly a professor of geology at the School of Mines at St. Étienne in southern France), and Victor Dupuy (later a mining engineer with the *Corps des Mines*). Dolomieu (accompanied by Cordier as his personal assistant) left Egypt after only eight months, because of illness and before the French army had gained significant access to the geologically more interesting region south of Cairo and the Nile delta. The task of pioneering geological exploration in Egypt was left largely to Rozière, whose studies ended in 1801 when a British expeditionary force defeated and expelled the French forces still in occupation. So far as is known, Napoleon was to make no further operational use of geologists.

However, following the French revolution of 1789, threat of a French invasion had soon wonderfully concentrated military minds in Britain. One consequence of this was the perceived need for accurate and appropriate topographical maps for the country as a whole. Accordingly, the Ordnance Survey was founded in 1791: as the Trigonometrical Survey of the Board of Ordnance. (The Board of Ordnance, under the presidency of the Master-General of the Ordnance, was until its abolition in 1855 a military body, responsible for the Royal Artillery and the Royal Engineers.) The first map to be published by the new Survey (in 1801) was a 1-inch-to-1-mile (1:63,360) map of Kent, the county most likely to face invasion from France.

During the Survey's primary triangulation of Great Britain, unacceptable differences were found between trigonometrical and astronomical fixing of station positions. Astronomical computations involved measuring the altitude of stars against a plumb line, and it was suggested in 1803 by the Survey's then senior officer (Lieutenant-Colonel William Mudge) that attraction by nearby hills or mountains, or inequalities of densities of rocks below the surface, might deflect the plumb line. In May 1814, the Master-General decided that it was 'expedient to institute a minute geological and mineralogical' survey (Rose 1996, 130) to

OUGS Journal 29 (2) Symposium Edition 2008, 10–17
© OUGS ISSN 0143-9472

support triangulation then in progress in Scotland, and appointed Dr John MacCulloch, a surgeon and the Ordnance Chemist, later a President of the Geological Society, to this duty (Rose and Renouf 2005). Initially it was expected that MacCulloch's work would be complete within a year, but he managed to extend it into compilation of a geological map of Scotland as a whole, with Ordnance funding until 1826 and after that, civilian Treasury funding until 1832. Published posthumously in 1836, this was the first geological map of any nation as a whole to result from an official government-sponsored survey.

Figure 1 Part of one of two cross sections made to accompany a coloured geological map (at scale of six inches to the mile, 1:10,360) of the County Londonderry parish of Aghanloo, Northern Ireland: seemingly the first military geological map/sections to be prepared for any part of the British Isles. This cross section, made in 1828 by Lieutenant W. Lancey, RE by order of Captain Pringle, according to its handwritten annotation, shows a sequence that in the original is partly coloured: from the bottom up, sandstone (brown), chalk (blue), 'amygaloidal' and basalt (both blotched carmine). For black/white illustration of part of the coloured map, see Herries Davies (1983) and Rose (1999, 2009a) (Reproduced by permission of the Geological Survey of Ireland, with kind assistance from Dr Matthew Parkes).

In the light of experience in Scotland, when the trigonometrical survey was extended from Great Britain into Ireland in 1824, it was resolved almost immediately to complement topographical mapping with geological mapping. Captain J. W. Pringle, a Royal Engineer officer and veteran of active service both in the Peninsular War and at the Battle of Waterloo (Rose 1999), was made founding Superintendent of the Ordnance Geological Survey of Ireland in 1826, with other Royal Engineer officers as his geological surveyors: Lieutenants J. E. Portlock (a veteran of the Niagara Campaign in 1814 to defend Canada from invasion by troops of the United States), G. F. Bordes, R. S. Fenwick, W. Lancey and A. W. Robe. They compiled at least one geological map and two geological sections (e.g. Fig. 1), for the parish of Aghanloo in County Londonderry, before the survey was discontinued in 1828. It was re-activated in the 1830s (Herries Davies 1983), and continued under military direction until 1846, led first by the then Captain J. E. Portlock, and later by Captain Henry James.

In England, Ordnance funding in the 1830s supported the fieldwork of H. T. De la Beche (Rose 1996), and when the future British Geological Survey was founded under his directorship in 1835, it was as the Ordnance Geological Survey: a paramilitary organization, whose officers wore blue uniforms. It did not become a civilian organization until 1845, when responsibility for its funding and direction was transferred to the Treasury (*see Sharpe, this volume, page 88*).

Neither De la Beche nor his successor in 1855 as director of the 'British' Geological Survey, R. I. Murchison, had benefited from a university education (Rose 1996, 2009a). Both had, however, attended the Junior Department of the Royal Military College, and it is significant that military education in Britain was largely a product of the French Revolutionary and Napoleonic Wars. The Royal Military Academy had been founded at Woolwich in 1741 to provide teaching (especially in mathematics) for cadets aspiring to commissions in the Royal Artillery and Royal Engineers (the 'Ordnance' corps), but military training establishments for army officers in general were not founded until 'world' wartime. In 1799, the Senior Department of the Royal Military College (which in 1858 became the Staff College, Camberley) was founded at High Wycombe, to train small numbers of young officers for higher command. In 1802, its Junior Department was founded at Great Marlow, also in Buckinghamshire (moving to Sandhurst in 1812), initially as a school for the sons of army officers but soon to provide an education for cadets seeking commissions as officers in the infantry and cavalry. In 1810, the East India Company founded a college at Addiscombe in Surrey (Fig. 2) to educate potential officers for its army in India. In 1812, a School of Military Engineering was founded at Chatham, ultimately to provide technical training for all ranks of the Royal Engineers.

Figure 2 The East India Company's military college (now demolished) at Addiscombe, Surrey, where teaching of geology was introduced into the curriculum by John MacCulloch in 1819. Publication of his textbook (the first British geology course book) was supported by the Company's directors in 1821 (from Vibart 1894).

The founding of these institutions created significant opportunities for geological teaching and learning (Rose 1997, 2009a). By 1819, geology was taught in England only at the universities of Oxford (by William Buckland) and Cambridge (by Adam Sedgwick). From 1819 to 1835 it was taught also at Addiscombe (by John MacCulloch), and, about 1820, briefly at Sandhurst (by Richard Phillips). About the middle of the century it was taught more widely: at Addiscombe, by D. T. Ansted from 1845 to 1861; at Woolwich by James Tennant from 1848 to 1868; at Camberley from 1858 to 1882 and at Sandhurst, from 1858 to 1870 by T. Rupert Jones (and later at Camberley by a Major Mitchell and then Lieutenant-Colonel Charles Cooper-King); and at Chatham from about 1888 to 1896 by A. H. Green. Of these, only Rupert Jones held a full-time appointment to teach geology at a military institution; others were visiting lecturers or taught geology only as a subsidiary subject. However, it is evident that during the 19th century military training establishments provided career opportunities for a significant amount of geological teaching, and that this teaching helped spread an awareness of geology among a large number of British army officers.

The Great War 1914–1918

By the end of the 19th century, perception of the military applications of geology had waned, and teaching in the subject lapsed. In the Great War of 1914–1918, the British army was to make use of a very few, highly qualified geologists in uniform, rather than attempt to give large numbers of officers an elementary understanding of the subject (Rose and Rosenbaum 1993a, 1998).

The first such geologist to be appointed was Lieutenant (later Captain) W. B. R. King, who served from June 1915 on the Western Front through Belgium and northern France, as the geological adviser for water supply on the staff of the Chief Engineer (later Engineer-in-Chief) at General Headquarters of the British Expeditionary Force (Rose 2004b, 2004c). At its peak, the Force comprised five armies and in total about 1.5 million men, plus half a million horses and mules. There was a considerable demand for potable water (typically 10 gallons per man or animal per day) in a region where civilian supplies were partly disrupted by military operations and surface waters were locally insufficient or sometimes polluted by ordure, munitions or bodies. Demand was met by innovations that included the first operational deployment of mobile rigs capable of drilling deep boreholes to extract groundwater; use of air lift pumps to raise water quickly from such depths; and maps prepared on the basis of geological data to guide the choice of drilling sites for new wells and the assembly of appropriate water supply equipment prior to campaigns to advance into new territory. ‘Bill’ King pioneered a variety of groundwater prospect maps that guided emplacement of more than 470 military boreholes (Rose 2009b), especially through Cretaceous Chalk in the provinces of Picardy and Artois in northern France. Maps at scale of 1:250,000 (e.g. Fig. 3) were used for general planning, maps at 1:100,000 (Anon. 1922, fig. 18) and 1:40,000 for more

Figure 3 Map of the Somme Valley and neighbouring districts of Northern France, dated 1918, showing contours of the surface of the Chalk marls in metres referred to sea level, original at a scale of 1:250,000: one of a variety of maps prepared by geologist Lieutenant W. B. R. King to guide development of groundwater to support British military operations on the Western Front (from Anon. 1922, at reduced size).

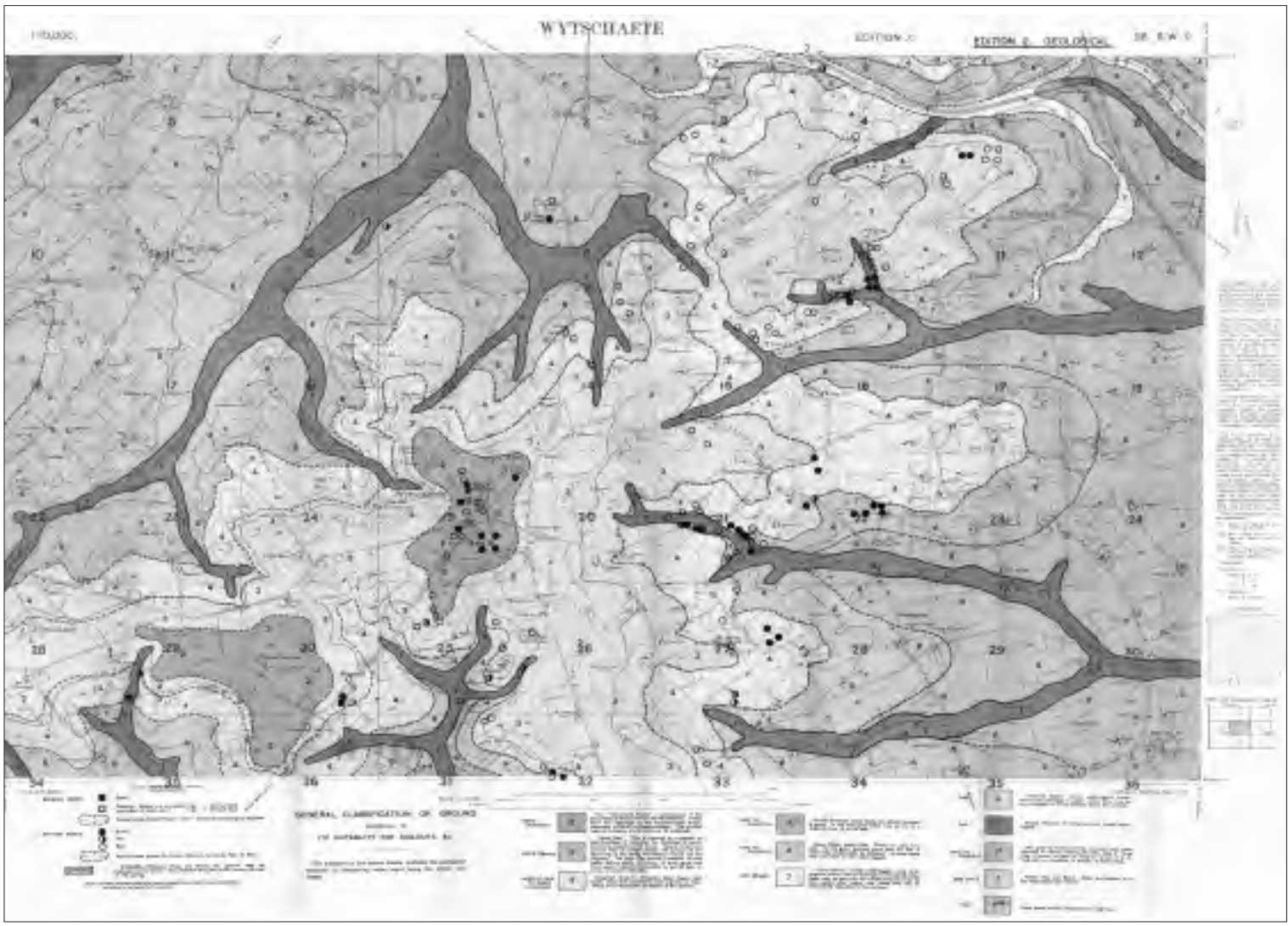

Figure 4 Geological map of Wytschaete, Belgium, dated 1918, original at a scale of 1:10,000: an example of a map set covering the Wytschaete-Passchendaele ridge near Ypres showing classification of ground according to its suitability for the construction of dug-outs — arguably the earliest medium-scale British 'engineering/environmental geology' maps to be published. For illustration showing original colours (shades of red for dry ground, blue for wet, and purple for alluvium), see Rose 2004d (from Anon. 1922, at reduced size).

detailed local use. German and American military geologists also necessarily developed maps for similar purposes in their operational areas of the Western Front, but American military water supply maps and reports (initiated only in 1918) adopted much of the style set by British precedents.

From May 1916, a second geologist was employed as such by the British Expeditionary Force: Major (later Lieutenant-Colonel) T. W. Edgeworth David, who arrived with the Australian Mining Battalion he had himself helped to raise (Brannagan 2004). Already a greatly distinguished geologist (and professor at the University of Sydney), David served as geological adviser to the Controllers of Mines of the British First, Second and Third Armies until September 1916, when he was transferred to the Inspector of Mines Office at General Headquarters. His role throughout the early phase of the war was to guide military mining: the excavation of tunnels from the British front line forward beneath enemy positions to enable explosive charges to be detonated beneath those positions as a prelude to infantry attack, or to counter enemy mining. At the peak of tunnelling activity, this involved the use of some 25,000 British and Commonwealth troops, and David guided their activities by use of geological maps, sections and reports. In the latter part of the war, when it became the practice to hold the front line more by artillery firepower than by infantry manpower, excavation was focused not on mine tunnels but on 'dug-outs' to shelter troops from artillery and mortar bombardment. Innovations to guide dug-out construction included publication of a set of 12 maps for part of western Belgium, in which the geological strata were classified according to their suitability for dug-out construction: 'good' (dry) strata coloured in shades of red, 'bad' (wet) strata in shades of blue (Fig. 4). Printed by the Ordnance Survey in England at Southampton, at scale of 1:10,000, this was the first set of 'engineering geology' maps to be published in the UK, certainly at such detailed scale.

The 'Second' World War 1939–1945

Both King and David returned to their pre-war civilian occupations at the close of hostilities, King to the Geological Survey of Great Britain before appointment to a teaching post in the University of Cambridge (and later as Professor of Geology at University College London), David to his professorial post at the University of Sydney.

When World War II broke out in September 1939, King was immediately called-up from the Army Officers Emergency Reserve to serve with the new British Expeditionary Force in

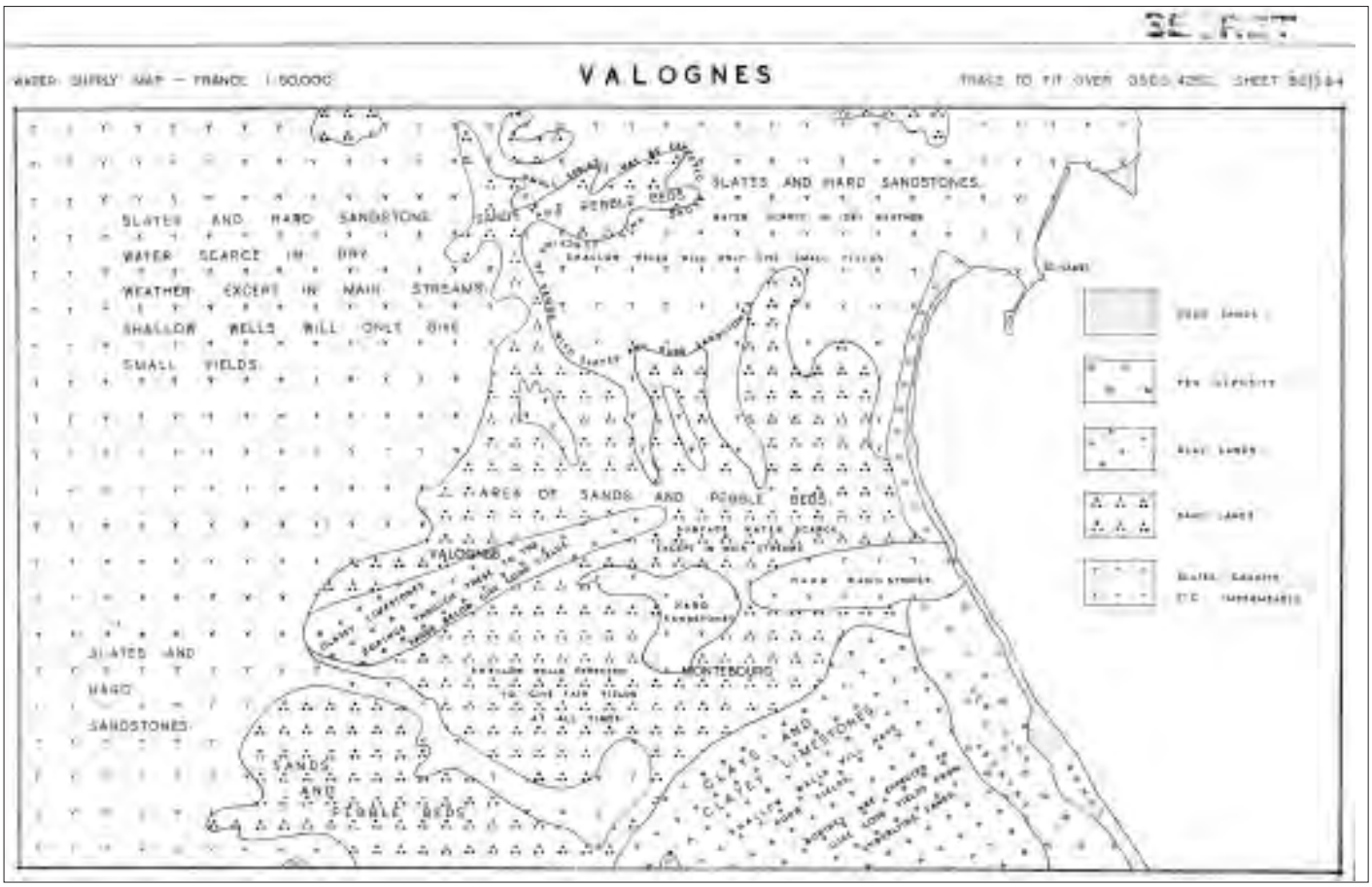
SECRET
VALOGNES
SLATES AND HARD SANDSTONES
WATER SCARCE IN DRY WEATHER EXCEPT IN MAIN STREAMS
SHALLOW WELLS WILL ONLY GIVE SMALL YIELDS
AREAS OF SANDS AND PEBBLE BEDS
SLATES AND HARD SANDSTONES
SANDS AND PEBBLE BEDS
CHALK AND CHALKY LIMESTONES

Figure 5 'Secret' (but now declassified) water supply trace map printed as a transparent overlay at a scale of 1:50,000 to fit over Valognes sheet of topographical map series GSGS 4250: an example of one of the simplest of 25 groundwater prospect maps of northern France prepared at this scale in 1943/1944 to guide the Allied liberation of Normandy. See Rose et al. *2006, Robins* et al. *2007 and Rose* et al. *2009 for illustration and description of other sheets in this series (a map preserved in the Lapworth Museum of Geology, University of Birmingham, scanned by Jon Clatworthy and reproduced with permission).*

France (Rose and Rosenbaum 1993b, 1998; Rose, 2004c). He did so until May/June 1940, when most of the Force was evacuated via Dunkirk. Back in England, he was joined later that year by one of his former Cambridge students, by then lecturing at Cambridge: F. W. Shotton (Rose and Clatworthy 2008a). Shotton was posted to the Middle East in May 1941, where he served with distinction as a military geologist until complete Allied victory in northern Africa in 1943. However, in September 1943 he was recalled to England, in the following month to succeed his former mentor 'Bill' King as the geologist at Headquarters 21st Army Group planning for the Allied invasion of Normandy (Rose and Pareyn 2003).

'Fred' Shotton developed a range of geology-based geotechnical maps (Rose *et al.* 2006), many of them projects initiated by 'Bill' King. Maps of the landing beaches at a scale of 1:5,000 indicated natural hazards to cross-beach vehicle mobility, notably areas of soft peat predicted to lie beneath the sand cover. Maps of northwest Europe at 1:1,000,000 showed the varying suitability of ground for the rapid construction of temporary airfields, and larger-scale maps guided the site selection and rapid construction of the numerous airfields necessary to maintain Allied air superiority over the battlefield. Groundwater prospect maps were prepared as tracing overlays for topographical maps to guide the enhancement of potable water supplies for base installations from new wells and boreholes, at a scale of 1:50,000 for coastal areas, from the Cherbourg Peninsula eastwards to Calais, and at 1:250,000 for most of northern France east into the Low Countries.

These and other maps prepared for the subsequent highly mobile campaign have been described and extensively illustrated (in colour) by Rose *et al.* (2006). The water supply maps, prepared as tracing overlays in black ink, have been more fully described by Robins *et al.* (2007), and other examples of maps prepared specifically by 'Fred' Shotton have been illustrated by Rose and Clatworthy (2008a). Water supply maps developed by British military geologists for the NW European campaign as a whole are the subject of a publication in press (Rose *et al.* 2009).

Figure 5 illustrates one of the 25 maps printed at 1:50,000 for coastal areas, a sheet not illustrated in any other publication. Printed in September 1943, and so presumably prepared by 'Bill' King rather than by 'Fred' Shotton, it depicts part of the eastern coast of the Cotentin Peninsula, south of Cherbourg. Part of the Armorican Massif, whose bedrock in general comprises strong crystalline basement: largely granites, schists and 'grits' (highly indurated medium to coarse-grained sandstones) of Precambrian and Palaeozoic age, here impermeable slates and hard sandstones are partly overlain by Quaternary sands and clays. Little of the area is suitable for the development of groundwater supplies by means of deep boreholes. The Cotentin Peninsula was progressively occupied following D-Day, 6 June 1944, by American troops, while Anglo-Canadian forces seized the Calvados region to the east. Here the Mesozoic sediments (especially mid-Jurassic limestones) that formed the western margin of the Paris Basin yielded water to at least 25 military boreholes sited mostly on the basis of maps in the same series, but which were able to depict

both the major aquifers and contours for the base of the aquifers, to indicate maximum potential drilling depths, drilling speeds and stores required (Robins *et al.* 2007).

Figure 6 illustrates one of the 13 maps printed at 1:250,000 for northern France into the Low Countries, again a sheet not illustrated in any other publication. Undated (but probably prepared slightly before April 1944; Robins *et al.* 2007), this map was one of four in the set prepared with geological guidance from 'Fred' Shotton. Although details of its complex key cannot be read at the much-reduced size adopted for the figure, it can be seen on the map that the large area to the west (left) comprises part of the Armorican Massif (like Fig. 5), whereas the smaller area to the east reveals the western margin sediments of the Paris Basin, unconformably overlying Armorican basement. Maps at this scale guided the emplacement of British military boreholes in Belgium in late 1944, as Allied forces advanced eastward. Coverage was extended farther to the east, across northern Germany, by nine maps at this scale prepared in England between November 1944 and May 1945 by the Geological Section of the Inter-Service Topographical Department (ISTD) — to ease pressure of work on Shotton as the 'field force' geologist. Together the 1:50,000 and 1:250,000 scale 'water supply' maps are significant as the first British attempt to produce groundwater development potential maps for a large area (and the 1:50,000 maps at detailed scale), and as the precursors of modern-day groundwater harvest potential maps.

ISTD, a British military unit primarily of geographers drawn from the army, Royal Navy, Royal Marines and Royal Air Force, under Royal Navy auspices, was based at Oxford from October 1940. It provided terrain intelligence to guide planning of Allied military operations in both Europe and the Far East (Rose and Clatworthy 2008b). From November 1943 until disbandment post-war in 1946, Royal Engineers geologists, as such, formed part of its establishment to assist the preparation of reports and maps. Early reports were illustrated by pre-war geological maps reprinted by the Geographical Section, General Staff, later reports by new simplified geological maps, usually accompanied by one or more thematic maps (as extensively described and illustrated in colour in Rose and Clatworthy 2007). An airfield suitability map for Bulgaria and soils maps for both the Middle Danube region (Hungary) and Austria were printed in colour, and groundwater (*cf.* Fig. 6) and soils maps prepared as tracing overlays for use with topographical maps for parts of Germany. Simplified geological

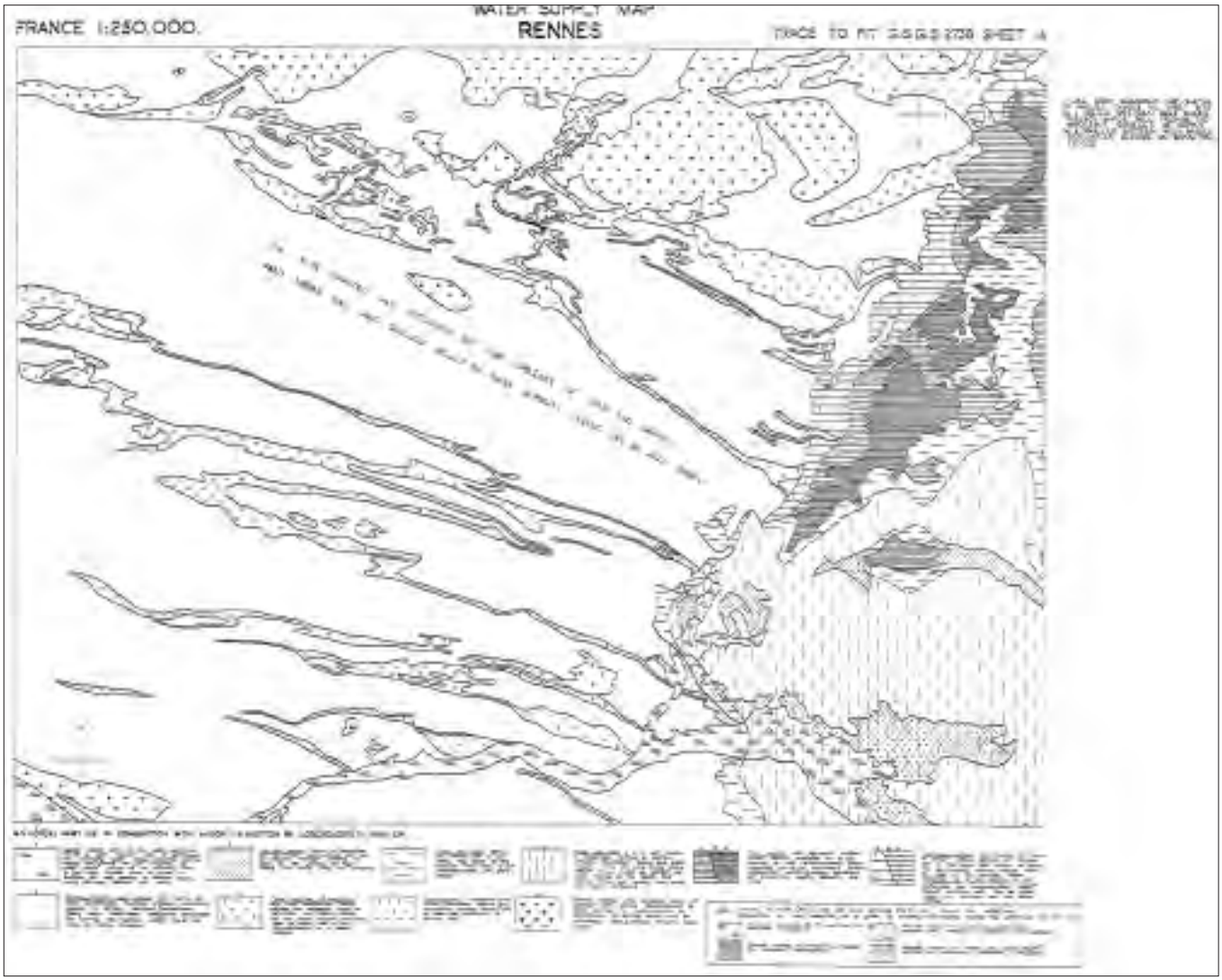

Figure 6 Water supply trace map printed as a transparent overlay at a scale of 1: 250,000 to fit over Rennes sheet of topographical map series GSGS 2738: an example of 22 groundwater prospect maps prepared at this scale in 1944/1945, covering much of northern France, Belgium, and northern Germany to guide Allied military operations in the NW European Campaign. See Rose et al. *2006, Robins* et al. *2007, Rose and Clatworthy 2008a and 2008b, and Rose* et al. *2009 for illustrations and description of other sheets in this series (a map preserved in the Lapworth Museum of Geology, University of Birmingham, scanned by Jon Clatworthy and reproduced with permission).*

maps with an extensive key to rock properties of military significance were prepared for Sumatra, Borneo, Formosa, the Kra Isthmus region of the Burma/Siam (Myanmar/Thailand) peninsula, Siam (Thailand) and Indo-China, Java, Hainan, and the Hong Kong to Canton region of China. They were mostly at a scale of 1:1,000,000 but in varying styles, to innovatively indicate terrain features of specific military significance. Maps to indicate the suitability of ground for rapid construction of temporary airfields were printed at scales between 1:250,000 and 1:1,000,000 for many of these regions, based on ground features and predicted soil permeability. Although even at the peak of activity there were no more than 12 earth scientists within the Geological Section ISTD, far fewer than the large numbers of geologists similarly employed by armed forces of Germany and the United States of America (Rose and Nathanail 2000), like the similar number of British military geologists serving in India (Rose 2005a) they helped to pioneer the discipline of terrain analysis — a discipline that was to evolve rapidly after the war for both military and civilian (land development) use.

Conclusion

Warfare at the beginning of the 19th century provided a stimulus in the UK to the innovation of national geological mapping in Scotland, Ireland and England/Wales with military funding, and developments in military education, which soon came to include geology as a small but widely taught component. Although national geological mapping was transferred to civilian auspices before the mid-century, and significant teaching of geology took place in universities rather than in military establishments by its end, perceived military applications had helped to promote the science of geology at this early stage of its history in the UK.

The Great War of 1914–1918, with its primary focus on relatively static conflict along the Western Front, provided the stimulus that generated innovative development both of groundwater prospect maps and also engineering geology maps, skills that the senior authors in both cases were to take with them to university professorial appointments after the war and so potentially to influence their students. Such skills were certainly of value to the Allies in the Second World War, if little evident in academic publications between the wars.

The Second World War, 1939–1945, was characterized by more widespread and more mobile campaigns. These provided the stimulus for further mapping innovation, not only for extended development of groundwater prospect maps but also for creation of other geology-based maps, which interpreted ground conditions for specific military purposes, such as site selection for the rapid construction of numerous temporary airfields. Partly as a consequence of the impetus given by wartime innovation, the disciplines of hydrogeology and terrain analysis were to evolve rapidly after the war.

Geology, like many other sciences in the UK and elsewhere, gained some impetus from world wars as a catalyst for innovation.

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Book review

Piccardi, L. and Masse, W. B. (eds) 2008 *Myth and Geology*. London: The Geological Society of London Special Publication 273 (ISBN 978 186239 216 8; hardback, 340pp; £90)

"Geomythology is the analysis of myths to learn about geological events portrayed in them." — Wikipedia

This book comprises 25 individual papers, most of which were presented to the first S. I. G. Symposium at the '32nd International Geological Congress' in 2004.

The two editors, together with contributing authors Barber and Barber (9ff) discuss the nature of myths, whether their origin is based in religion or in folk memory, the different ways in which these have been interpreted and valued historically, and their relevance to modern scientific thought. References to specific myths are scarce, and appear incidental to the main focus of the text.

The keynote paper by Vitaliano, who incidentally coined the term geomythology, defines the subject in a clear and accessible manner, although her reference to the Loch Ness Monster as a geological mystery is puzzling. A number of contributors seem to identify a wider definition of the subject: Roberts ('Genesis chapter 1 ...' [39ff]) and Lanza and Negrete ('Earth education ...' [61ff]), in particular, offer highly individual interpretations of the information that they present.

Some papers appear to be well researched and presented geologically but fail to offer a convincing mythological connection. By contrast Triponov ('Soddom and Gomorrah ...' [133ff]) very reasonably offers four hypotheses based on the evidence he presents, although his chosen conclusion might not appear to be the most likely. This is nevertheless an interesting and thoughtful paper.

Other papers of interest and worth attention, in that they successfully present the myth alongside verifiable geological evidence in a convincing manner, are Morner ('Fenris wolf ...' [117ff]), Bourrouilh-Le Jan ('Band-e-Amir Lakes ...' [121ff]) and Aringoli *et al.* ('Sibbila Appennenica ...' [329ff]).

Chandrasekharam ('Geomythology of India ...' [29ff]) very interestingly shows that the Hindu faith is so integrated into the life of believers that they find no dichotomy in accepting the ancient mythological explanations of geological phenomena while at the same time also accepting modern scientific proofs.

While not strictly relating geology to specific myths Piccardi, Vittori and Folloni write (51ff) of the ongoing CLEMENS database project, which is collecting together all known records and oral traditions of environmental incidents and hazards in the Mediterranean region throughout Roman and medieval times, a project that should be of great value to future research.

Following a SIG symposium of this nature it is perhaps understandable that the editors would wish to include the work of as many contributors as possible. The reader though, could perhaps be deterred from considering papers offering carefully presented research and conclusions by the minority of less logically presented work. In all however, this is an interesting book, which could have been improved by applying stricter editorial control.

— Vic Rayner

The role women have played in developing the science of geology 1797 to 1918–19 in Britain

Professor Cynthia Burek (University of Chester, Parkgate Road, Chester College CH1 4BJ)

A title change

During the preparation of this paper, before I delivered my talk at the OUGS Symposium at The Royal Holloway College, Egham, I changed the its title very slightly from the original abstract.*

Why did I change the title? I had read Melvyn Bragg's Twelve Books that Changed the World (2006) a couple of months previously, and two of the books that he chose to include were written by women, one in 1792 (Mary Wollstonecraft's *A Vindication of the Rights of Women with Strictures on Political and Moral Subjects*) and one in 1918 (Marie Stope's *Married Love*). So, why did I choose 1797 instead of 1792? Well, because geologically, it is an important year. James Hutton died in 1797 and Charles Lyell was born in the same year, but more importantly, Mary Wollstonecraft, the author of that 1792 book died in 1797. Also, by choosing these dates I could include Mary Anning, because she was born in 1799.

Why did I choose 1918–1919? In 1918 women over 30 years old got the vote; and also because in the same year Marie Stopes (1880–1958), of whom you will read much more below (*see Chaloner, this volume, page 26*), published her book *Married Love*. And of course Marie Stopes was a geologist, initially specialising in Palaeobotany, especially in coal balls. The final volume of Gertrude Elles' (1872–1960) and Ethel Wood's (1871–1945) famous book on graptolites was also finally published in 1918.

Finally, I have extended the date to 1919 in order to include the first female Fellows of the Geological Society, a subject that I cover in depth in the forthcoming book on the origins of the Geological Society of London (Lewis and Knell (eds) in press).

Introduction

First, it is interesting to note the preliminary results of some research that Dr. Bettie Higgs (another Open University tutor in Earth Science) and I have been undertaking over the past few years. This is to assess the knowledge of the public at large in the field of the history of women in science (Burek and Higgs 2007b). It involves filling out a short questionnaire and has been carried out in the UK, Ireland, France, Spain, Germany and a few examples each from Italy, Greece, Poland, the Netherlands and the Scandinavian countries. To date, nearly 700 questionnaires have been filled out and returned. Basically, the questionnaire asks people to name ten famous female scientists. Initial analysis across Europe indicates that the only female scientist known, if indeed any are cited at all, is Marie Curie (1867–1934). Of all people asked, 72% named Curie, and more often than not named only her.

When we come to geologists, the only female geologist ever named is Mary Anning (1799–1846), and people do not always remember her name. They remember her with a phrase such as, 'Oh, it's that dinosaur lady.' Or, 'that fossil lady who lived down in Lyme Regis in Dorset.' Indeed an analysis of 550 people questioned showed that 10% named her. So I think that I, and indeed all of us, have a job to do to raise awareness of the female contribution to the history of our science.

* *Editor's note: The original title of the abstract is 'The role women played in developing the science of geology'.*

However, in the remainder of this paper I will examine the roles that women played in the development of geology over 120 years, from 1797 to 1919. Many of these roles are described and examined in Burek and Higgs (2007a), and I would refer you to this work for more detail.

How did the research for this book come about? It was an idea that had been brewing for some time and was put to the History of Geology Group (HOGG) by myself, and with the support of the Geological Society of London and sponsorship from the UK Resource Centre for Women into Science, Engineering and Technology, a conference was held in London in November 2005. Slowly, I think that there was a general recognition that there were a lot of women through history who had contributed through different roles to the development of our science. Their work had either been forgotten, or had been mislaid, and we needed to find out more about them and the roles they played. We (the organising committee of the conference: Cynthia Burek, Bettie Higgs and John Mather) made a decision very early on, that we would only look at women that were dead, or as Betty Higgs prefers to say, "those no longer able to tell their own story" (Burek and Higgs 2007b).

So what roles did they originally play between 1797 and the end of the First World War? Initially, they adopted the roles of collectors or illustrators, often as family assistants. Later traditional roles became those of writers and teachers, and museum curators and researchers. Photographers and translators are perhaps two that do not spring readily to mind.

I will examine a few examples of each of these roles, and then describe some of our case studies.

Family assistants

There are many examples of family assistants from this time period: from Murchison's wife, Charlotte Hugonin (1789–1869), who acted as her husband's illustrator and editor, to Edward Seuss's wife, Mary, who acted as a chaperone on fieldtrips, they covered many different roles. Anne Phillips (1803–62), for example, assisted her brother, John Phillips (Morgan 2007), and there are many other examples of mixed-gender family relationships pushing geological knowledge forward.

Collectors

There are numerous examples of collectors during this time period as well: from Etheldred Benett, who was really the first female geologist, not Mary Anning as is sometimes stated (Burek 2001), to Elizabeth Anderson (Mrs Gray), a great fossil collector from the Girvan area in Scotland. Etheldred Benett (1776–1845), who was born 23 years before Mary Anning, did a lot of detailed stratigraphical work in Wiltshire and deposited her sections in the Geological Society Library in 1813. She was one of the first people, probably the first, to produce a geological section of a quarry. She did not do the measurements herself but ordered quarrymen to do it for her, which is what you do as the daughter of the local squire. Her collecting focused on local fossils from the southwest part of Wiltshire, near her home in Warminster, and the quality of her collection led to it being displayed in the Imperial

OUGS Journal 29 (2) Symposium Edition 2008, 18–25
© OUGS ISSN 0143-9472

Collection of the Czar in St Petersburg, Russia. Mary Anning was of course also a great collector and was relatively well known. There were others who do not have such a high profile, such as Elizabeth Gray (neé Anderson; 1831–1924), the Philpott sisters, Mary (1776–1838), Elizabeth (1779–1857) and Margaret (1786–1845), and Elizabeth Carne (1817–1873). All were avid fossils collectors, except Carne, who instead collected minerals and set up a mineral museum in Penzance, Cornwall.

Illustrators

The next role women from this period undertook was that of illustrators. Three examples are Mary Mantell (1795–1869), who was the wife of Gideon Mantell (1790–1852) and undertook several drawings for his first book; Mary Buckland (1797–1857), who was born Mary Moorland, and worked with Georges Cuvier; and Jane Longstaff (neé Donald; 1856–1935) who illustrated her own papers for the *Quarterly Journal of the Geological Society*. Her drawings of the gastropods that she collected are very clear and accurate. Emma Parkinson (1788–1867), daughter of James Parkinson, also did drawings for her father, who was one of the first founders of the Geological Society.

Photographers

What about photographers? This is an interesting and unusual role.

However, before describing the role of women and photography in geology, the role of the Geologists' Association (GA) must be acknowledged in this area. The GA is a very different society and has a different organisation to that of the more traditional Geological Society of London (GS). Whereas the GS (the oldest geological society in the world) is a professional body and is recognised as such, the GA, by comparison, has a wider remit and caters more for the amateur (Burek 2008; Green 2008). The GA holds an extensive archive of photographs taken over the years by their members, many of whom were women. These are not professional photographs, rather, amateur 'snaps'. In Burek and Prosser (eds) (2008), in a chapter entitled 'The role of the voluntary bodies in the history of geoconservation', I explore in detail the differences between the Geological Society and the Geologists' Association (Burek 2008).

Two important female photographers provided a visual archive of sites and people: Mary Rosse (1813–1885) and Mary Sophia Johnston 1875–1955), the latter being one of the first female Fellows of the Geological Society and also an avid supportive member of the Geologists' Association. More information about Mary, 3rd Countess of Rosse, who operated in Ireland, can be found in Higgs and Wyse–Jackson's (2007).

Figure 1 Mary Sophia Johnston (1875–1955).

Mary Sophia Johnston was the voluntary illustrations officer of the GA and she was also appointed their unofficial photographer. It is her diligence and fortitude that we have to thank for most of the pictures that I use, and also for that fantastic GA archive that Marjorie Carrick brings out at every GA reunion. This archive is a wealth of photographs of early GA geological field trips — and many of them include women, who were encouraged to go on these trips. In fact they were allowed to become members of the Geologists' Association from the very beginning, in 1858 (Burek 2007; Green 2008).

Writers

As writers women also played an important role. Again, just four examples illustrate the broad spectrum that writing as a specific scientific genre could cover.

Arabella Buckley (1840–1929) was secretary to Charles Lyell until he died in 1875, after which she took to writing full time for children. For example, her book *The Fairyland of Science* was based on a series of lectures that she gave to children. Within the book, one chapter is devoted to the history of a piece of coal. As secretary to one of the leading geologists of the time, she was up to date with her knowledge and sought to pass it onto to those around her.

Another writer in this category was Grace Anne Milne (1832–1899), otherwise known as Lady Prestwick, wife of Joseph Prestwick and niece of Hugh Falconer (Mather and Campbell 2007) She wrote chapters on geology in children's magazines.

Thus, both of these writers wrote for an amateur but interested and young audience.

Ethel Gertrude Woods (neé Skeat; 1865–1939) was a researcher and head science teacher at Queen's School in Chester, but when she married she had to resign from this post, as was customary and obligatory at the time. She moved to Cambridge where her husband, Professor Henry Woods, was the famous palaeontologist. There she wrote a book on physical and human geography, which was regarded as an exemplary textbook at the time (Woods 1923).

Maria Ogilvie Gordon (1864–1939), about whom we will learn more later, was also a prolific writer. She wrote not only scientific material but also on other subjects, such as education and better conditions for women.

Figure 2 Maria Ogilvie Gordon (1864–1939).

Translators

Two of the main languages of science during this time were French and German. Many of the major geology books were not in English, and therefore not accessible to an English-speaking readership. Many scientists spoke other languages but not all of them. Therefore, translators who understood the science, and who were also able to translate other languages, were necessary. Maria Ogilvie Gordon, an Aberdonian lady, was a great linguist, as well as a great field geologist, having completed her PhD in German at Munich University and worked extensively in the Alps. I will expand on her other achievements later — but she is mentioned here because she translated the whole of Karl von Zittel's *History of Geology* into English.

Clementine Cuvier (1805–1827), one of George Cuvier's daughters (Orr 2007) was another translator. She translated and acted as an interpreter for her father, who understood but did not speak English.

Hertha B. C. Sollas (b. 1875), the older of Professor Sollas's two daughters, translated Seuss's *Das Antlitz der Erde* into the five volume *The Face of the Earth* (Wyse Jackson and Spencer Jones 2007).

Museum curators

Called by Patrick Wyse Jackson and Spencer Jones 'the quiet workforce' (2007), women curators worked both on national and local collections in such places as the Natural History Museum or in local county museums such as the Grosvenor Museum in Chester. Shindler (2007) discusses in detail Dorothea Bate's (1878–1951) story at the Natural History Museum, and there are many more examples: Elizabeth Carne in Cornwall with her mineral museum, Elizabeth Gray and her daughters in Scotland, and the Philpott sisters in Lyme Regis with their museum and collections. These women, their collections and their achievements are discussed in detail in Wyse Jackson and Spencer Jones (2007).

Higher education

Table 1 puts the roles of women into context in relation to higher education in England and Ireland. It lists important dates in the development of geology and in the availability and accessibility for women to enter higher education and to study geology:

Table 1 Women in higher education in England and Ireland.

1841 University College, London appoints Professor of Geology.
1849 Bedford College, London opens as one of the first women's colleges.
1864 Cambridge Open Exam opened to women.
1869 Newnham College and Girton College opened as the first two women's colleges in Cambridge.
1870 Elementary Education Act passed in Parliament.
1875 University College opened its doors to women.
1876 First British university degree awarded to a woman.
1879 University of London degrees opened to women.
1883 Owen's College, Manchester and Cavendish Labs, Cambridge opened their doors to women.
1886 Royal Holloway College (RHC) opened by Queen Victoria.
1898 University of London became a teaching university.
1900 Bedford College, London and RHC became part of London University.
1902 Trinity College, Dublin opened doors to women.
1904–7 Steamboat ladies sailed to Dublin.
1919 Sex Disqualification (Removal) Act passed in Parliament.
1948 Newnham College became part of Cambridge University.
1970 Equal Pay Act made into law in Parliament.
1975 Sex Discrimination Act made into law in Parliament.

University College, London appointed a Professor of Geology in 1841, a development that coincided with the beginning of the teaching of geology in British army institutions (*see Rose, this volume, page 10*). Catherine Raisin was the first woman to study geology there in 1875 (Burek 2007).

However, I would like to focus here on Bedford College, London, which opened its doors to women in 1849 in the guise of a Ladies College. In the history of women's higher education, this is quite early, and initially for the first 20 years of its life, Bedford College did suffer from not having suitably qualified women to attend the college. Thus it struggled to achieve the necessary level for degree work. Not until about 1875 did the increase in numbers to 100 students reflect an increase in the ability of the students to perform to degree level. It reached a much firmer footing in 1894 when it secured government funding.

Although University College, London did offer geology to women students, Bedford College was the first to offer geology in an all female student setting. Geology was not taught there as a single subject until 1885, when a geology department was established, but it was taught alongside geography from the beginning, in 1849 (Burek 2007).

An equally important date in education is the 1870 Elementary Education Act. This Act stated that primary education was to be compulsory throughout England. Therefore, suddenly, there was a demand for teachers. There had been governesses and educational institutions before, such as church schools, but from 1870 primary education was compulsory. So a sudden need for teachers encouraged women to get teaching qualifications. In 1875, University College, London opened its doors to females. At this time, the University of London was not a teaching institution but just set exams, so 1870 and 1875 are significant dates.

Exactly 100 year on, 1970 and 1975 are also dates for two further important pieces of legislation. The Equal Pay Act entered the statute books in 1970, and in 1975 the Sex Discrimination Act was passed in the British Parliament.

In 1900, Bedford College and Royal Holloway College both become part of London University. However, it was not until 1948, that Newnham College became part of Cambridge University. The University of London had led the way forward in the UK in awarding degrees to women.

Figure 3 Women receiving their Univeristy of London degrees in 1891.

Teachers

Ethel Skeat (later Mrs Woods)* was regarded both by her students and colleagues as an exemplary teacher, and was the second main teacher at the Queen's School in Chester (Burek and Malpas 2007).

Catherine Raisin (1855–1945), of whom we are going to hear more in another role, was at Bedford College in London and Gertrude Elles at Newnham College, Cambridge. Both were regarded as role-model teachers. Mary Heslop (1885–1955) and Margaret Gardiner (1860–1944), who are not as familiar perhaps as Raisin and Elles, were also both teachers, and both also published papers in the *Quarterly Journal of the Geological Society*. Margaret Gardiner did not become a GS Fellow, but Mary Heslop did, and the latter was one of the first members of the Geologists' Association as well. Mary Heslop taught in Newcastle upon Tyne; Margaret Gardiner at Aldeburgh School, which she founded in Suffolk.

Researchers

There are two problems that become apparent when researching this role. The first is that sometimes the continuity of the research record is lost owing to the woman's change of name upon marriage. The second problem is that, for a long time, if you married, you were required to leave your job, whether it was in education or in the civil service. Female researchers might, however, carry on with their research in a different and often hidden capacity. This was sometimes achieved through honorary status, or as unpaid work. An exception was Ethel Wood*, who had established her publishing career as a single woman. She managed to carry on with her research after she married and had changed her name, in this particular case to Ethel Shakespear. Her research was on graptolite classification and stratigraphy.

The problem of name change on marriage is an interesting one. How do the professional bodies and different organisations deal with it, especially if the author is already established? If we look at the Geological Society, for example, the first time that they had to deal with this occurrence was when Maria Ogilvie married and changed her name to Maria Ogilvie Gordon. Ogilvie was recognised as one of the most prolific Scottish geological writers of the late 19th century (Burek 2005), and at the time of her marriage to Gordon was already an established authoress. So the GS publishing committee made the decision to put her married name in brackets as (Mrs Gordon), beneath Maria Ogilvie in her byline. This practice provided continuity in tracing an authoress' publication record.

Catherine Raisin published more than 24 research papers, Maria Ogilvie Gordon more than 36 papers, and Jane Longstaff (1856–1935), of whom most people have not even heard, more than 20 papers.

On the other hand, many people have heard of Marie Stopes — but not as a geological researcher. Her reputation was made with the publication of her book *Married Love*, not as a prolific palaeobotanist (Chaloner 2005). Another example is Rachel Workman (1884–1954), later Lady MacRobert, who did her first degree at Royal Holloway College, and actually read geology (Burek 2009). Like Ogilvie, she published her research work in the *Quarterly Journal of the Geological Society*.

However, the first paper written by a woman and published by the Geological Society *Quarterly Journal* was in 1824. It is a note by Maria Graham (1785–1842) about an earthquake in Chile. It was then 38 years before the next paper by a woman was published, in 1862, by Miss Elizabeth Hodgson (1813–1877). Hodgson's paper was on plant remains in the Ulverston area in the Lake District.

A further 25 years then passed before there was a sudden influx of papers published by women in the *Quarterly Journal*. Between 1887 and 1907, only 13 women published 31 single-authored papers and six joint ones — and you might ask why there were so few over that 20-year period. The answer probably lies in the fact that the universities had started allowing women into their lectures, and suddenly, women were enabled to contribute to and conduct their own research. It was because from this time too that women were also being appointed to lecturing positions alongside their male colleagues, and therefore started to publish research papers in earnest, but research takes time.

Six women actually dominate the first 13 years from 1887: Jane Donald (later Mrs Longstaff), Gertrude Elles, Ethel Wood (later Mrs Shakespear), Mary Ogilvie Gordon, Margaret Gardiner and Catherine Raisin. It is interesting that each formed an alliance with a male colleague to read their papers for them at the Geological Society, because they were not allowed in to read them themselves. What were these alliances? Well, Catherine Raisin had her co-author, colleague and mentor Professor Bonney to read her papers, while Jane Donald asked John Goodchild, who was a Geological Survey member, to read hers.

What about the subject matter of the papers? Were they all the same? No they were not. Table 2 (*next page*) shows the list of varied subjects upon which they wrote. We perhaps might have expected them all to be on fossils and palaeontology, but they are not. Catherine Raisin, for example, wrote on metamorphism and serpentines, and Margaret Gardiner wrote about the Greensand bed at Thanet. In 1892, Maria Ogilvie Gordon wrote on Tyrol stratigraphy and had Charles Lapworth read her paper. These 'alliances' continued, of necessity, until the rules were changed and women were finally allowed to read their own papers.

We know that these women's work was recognised scientifically because the Geological Society awarded them money to continue their research. A learned society certainly does not give research money from its funds to a person in whose research it does not believe in and value. Therefore these women's role in forwarding the history of our science was duly acknowledged by the Geological Society at this time. The first woman researcher to receive GS funding was Catherine Raisin in 1893 (see Table 3, *next page*).

Women were not allowed to collect their money themselves until 1908, when Ethel Skeat was allowed to do so.

Catherine Raisin (1855–1945)

It is astonishing that Catherine Raisin is really one of the forgotten women of science, for she has so many 'firsts' associated with her name (Burek 2003). She was such an unusual lady. She was the first woman to be head of two departments at the same time — Botany and Geology, which she herself admits in her

** Editor's note: Ethel Gertrude Skeat became Mrs Woods in 1910; Ethel Reader Wood became Mrs Shakespear in 1906, later Dame. Gertrude Elles and Ethel Wood collaborated in their study of graptolites (see later in article). Both Ethels (Skeat/Woods and Wood/Shakespear) were at Newnham College, Cambridge together, and worked on the stratigraphy of north-east Wales.*

Table 2 First papers written by women and read to the Geological Society of London.

date read	*name*	*paper*	*reader*
1887 May 25th	Jane Donald of Carlisle	Notes on some Carboniferous species of M*urchisonia*	J. G. Goodchild of Geological Survey
1887 June 23rd	Catherine A. Raisin	Notes on the metamorphic rocks of South Devon	Prof. T. G. Bonney
1988 June 20th	Margaret I. Gardiner	The Greensand bed at base of Thanet Sands	J. J. H. Teall
1889 Feb 20th	Catherine A. Raisin	On some nodular felstones of the Lleyn	Prof, T .G. Bonney
1889 June	Jane Donald	Descriptions of some new species of Carboniferous Gasteropoda	J. G. Goodchild
1890 May	Margaret Gardiner	Contact — alteration near New Galloway	J. J. H. Teall
1891 February	Catherine Raisin	On the lower limit of the Cambrian series in NW Caernarvonshire	Prof. T. G. Bonney
1892 February	Jane Donald	Notes on new and little known species of Carboniferous *Murchisonia*	J. G. Goodchild
1892 June	Maria M. Ogilvie	Contributions to the geology of Wengen and St. Cassian strata in Southern Tyrol	Prof. Charles Lapworth

Table 3 Awards of research funds to women geologists, 1893 to 1908.

year	*name*	*award fund and amount*	*collected by*
1893	Catherine Raisin	Lyell £24 16s 3d	Prof. Bonney
1898	Jane Donald	Murchison £28 14s 3d	Mr Newton
1900	Gertrude Elles	Lyell £19 6s 0d	Prof. McKenny Hughes
1903	Elizabeth Gray	Murchison £22 15s10d	Dr Henry Woodward
1904	Ethel Wood	Wollaston £34 6s10d	Prof. Marr
1906	Helen Drew	Daniel Pidgeon Fund (undisclosed amount)	sent to her
1907	Ida Slater	Daniel Pidgeon Fund (undisclosed amount)	sent to her
1908	Ethel Skeat	Murchison £25 8s 4d	herself

correspondence was an enormous workload (Burek 2007). As already stated, she was the first woman to study geology at University College, London. She was also the first Vice Principal of a Higher Education College and the first woman to receive the Lyell Fund from the Geological Society of London. She was an invited guest at the centenary event at the Geology Society and she became a Fellow of the Geological Society at 64, so there's hope for us all!

One of Raisin's legacies is her teaching. She served as a role model to her students, who knew her as 'the Sultana', a nickname that shows both their respect and affection for her. She was an inspiration for her undergraduate students as well as for her research students: Helen Muir Woods (1895–1968), Irene Lowe (1890–died in India some time after 1931) and Doris Reynolds (1899–1985). This in itself is unusual, as there were so few women who had the position and ability to supervise research in geology.

Raisin was active in college life as well, as is shown by these contemporary statements in the Bedford College Magazine in the late 1880s and 1890s: "Students are indeed grateful for the amazing consideration that she has shown them in the arrangement of the timetable, and especially for her sympathy for the devotees of Hockey. The more so, as this necessitates two nine o'clock demonstrations and a nocturnal lecture." "Course of Lectures: Miss Raisin is now giving a very interesting course of lectures on the 'Ancient Volcanoes and Glaciers of North Wales' illustrated by means of the lime-light lantern" (Bedford College Magazine 1893). "Start of a new society called the Natural History Society. Miss Raisin was voted chair and then president" (Bedford College Magazine 1898).

Doris Reynolds says in her acceptance speech for her Lyell Medal: "It was Catherine Raisin who first interested me in geology and from whom I inherited my love for petrology. I owe very much to her long memory and unbiased teaching." (Reynolds 1960). Catherine Raisin had died, at the age of 90, fully 15 years before Reynolds wrote this obituary. Clearly Reynolds is thinking about Raisin's teaching.

Raisin's research legacy, which I have already mentioned, is her 24 scientific papers on metamorphic research and petrology.

Figure 4 Catherine Raisin (standing at far right) (1855–1945).

She was actually a very perceptive lady and often ahead of her time. Reading the letters in her archive you find her constantly questioning her peers on geological interpretations and her administrative superiors within the college, How many of us are still asking questions such as the following: 'What will happen to my slide collection when I retire?' Raisin could equally have said 'rocks'; or 'Why is there not more geology not taught in schools?'; or 'When do I have time to do research?'. How many of us at a teaching university today continue to ask these same questions? Or, for that matter: 'Why do I always get one-year contracts?'

The quality of Raisin's research is commented on in the award citation for the Lyell Fund: "Miss Raisin's excellent work, both in the field and with the microscope so far commends itself to the Council that they have readily made this Award … The considerable number of papers which the lady has contributed, both to the QJGS and the Geological Magazine, all within the last six years, is a proof of her industry, while the papers themselves indicate an excellent knowledge of Petrology and a good eye for country." (1893).

In summary, Catherine Raisin should be remembered for four reasons:

- Her research into petrology, especially metamorphic facies and their identification, especially of serpentines.
- Her analyses of thin sections, which were pioneering work at the time.
- Her dedication to female education and equality, so much so that occasionally she paid the fees for her demonstrators herself. She was very enthusiastic about her subject, and this enabled her to be an excellent teacher, and to instil her enthusiasm into her students.
- Her exemplary administrative capacities. How many people can run two departments at the same time?

Raisin's collections and archives are now at Royal Holloway College.

Gertrude Elles (1872–1960)

The second woman I want to talk about is Gertrude Elles.

Elles' career overlapped with that of Catherine Raisin, and they were both formidable characters. Both were remembered by everybody who knew them as inspiring teachers. Elles was born in Wimbledon (London) on 8 October 1872, although her ancestors were Scottish. She had an affinity for Scotland and spent much time there. In 1891, she attended Cambridge University, specifically Newnham College, at the age of 19, and received a first class honours degree in Geology in the Natural Sciences Tripos four years later. Working at the Woodwardian Museum in Cambridge, she became part of the team researching Lower Palaeozoic rocks and fossils and was awarded a scholarship from Newnham College to pursue this. She travelled to Sweden to study the Lower Palaeozoic rocks and fossils there.

Working under the editorship of Professor Lapworth (who named the Ordovician Period), she prepared the mammoth, two-volume monograph on British graptolites with her colleague Ethel Wood, and therefore the names Elles and Wood will always be linked to the study of British Graptolites.

Elles also received money from the Lyell Geological Fund of the Geological Society of London in 1900 (see Table 3) for her work on three classic papers on different genera of graptolites. Her research was described as, "adding much to our knowledge of the characters and range of those fossils" and "still more important paper on the graptolite-fauna of the Skiddaw Slates"; and even before the third paper was published, the President of the Geological Society, Sir Archibald Geikie, remarked about "her knowledge of the Wenlock shales of the Welsh borderlands" (Geikie, 1900). Although she was awarded the fund in absentia — because of the rules of the Geological Society against women attending meetings — her professor, McKenny Hughes, when receiving the award on her behalf, stated that she "has shown herself to be a clear-sighted stratigraphist and an astute palaeontologist over a much wider field than might appear, from the mention of the work for which this Award has been made" (McKenny-Hughes 1900). And it is important to remember that this praise was from the founder of the Sedgwick Museum in Cambridge.

Elles was also interested in other geological issues, including the stratigraphy of Lower Palaeozoic rocks in general, and those of Scotland in particular. She also saw the importance of the wider context of fossils and studied them as communities. Her presidential talk to the 1923 British Association Section C was, for example, on stratigraphical palaeontology as highlighted by both the evolutions of ancient fossil and modern faunal groups. In this regard she was expressing the ideas of the palaeontologists with whom she was or had been associated, and with whom she had discussed these issues, such as Ethel Wood (now Dame Shakespear) and indeed Ethel Woods, as well as Lapworth. During her lifetime, her research is especially notable for significantly raising the awareness and identification of the extinct fossil group of graptolites.

Elles was the first female to be awarded a university readership at Cambridge University, at the age of 54. Outside geology, she was awarded an M.B.E. for her services to the British Red Cross during the First World War, for at this time it was common for middle-class women in Britain to carry out 'Good Works' alongside paid employment. As well as being remembered as an enthusiastic teacher, she was a lover of music and of fishing, and as a superb role model for both men and women who need dedication and determination to study extinct organisms in detail.

Figure 5 Gertrude Elles (1872–1960).

It is fitting to remember that both Gertrude Elles and Ethel Wood were considered suitable for the work because they were women. "One qualification for the task of monograph compilation then, was a capacity for drudgery" (as Lapworth himself had reputedly said) (Gould 1998).

Studying graptolites — those small indistinct creatures — was considered too tedious for men, who were perceived at the time to lack the perseverance to detail necessary to carry out the work. The second point was that the reward for production of the treatise was not financial, but "the gratitude of future, if not present generations" (Woodward 1894). It is significant that Elles and Wood took more than 12 years to complete the highly detailed and subsequently acclaimed two-volume work *A Monograph on British Graptolites*. Elles appears to have realised (or acknowledged) the significance of her award in her reply to the Geological Society in 1900, when she stated, "I will strive my very utmost to make the work which I may do in the future worthy of the confidence which such an Award seems to imply". She certainly did that and much more.

Gertrude Elles died on 18 November 1960 in a nursing home in Helensburgh, Scotland at the age of 88 after an obviously very full life. In summary, throughout her life, she had made a significant contribution to both the status of women in science, especially in the earth sciences, had acted as a role model, and had made an enormous contribution to the understanding of graptolites as zone fossils within their wider fossil communities.

Conclusion

Four women, in particular, stand out as having contributed significantly, I think, to the growth of geology: Gertrude Elles and Ethel Wood for their work on graptolites, Maria Ogilvie Gordon for her work on the structure and stratigraphy of the southern Tyrol, much of it published in German, and Catherine Raisin for her work on metamorphic facies. You could argue for other people, such as Mary Anning or Etheldred Bennett; but for me, these four stand out during this time period. Later Emily Dix, Doris Reynolds, Janet Watson and Marie Tharp should also be remembered.

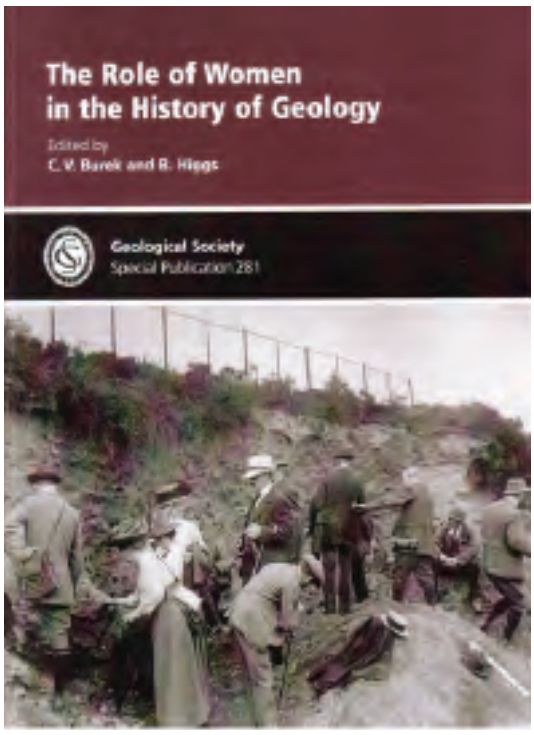

Figure 6 Front cover of The Role of Women in the History of Geology*, edited by C. V. Burek and B. Higgs.*

To summarise, until 1875, women were definitely volunteers and helpers. After 1875 they became more professionalised, if you like; they became qualified. Throughout the whole period under discussion, women rarely carried on working after marriage, although some carried on with their research often privately and unpaid. They contributed in many different ways, as we have seen, but in the main much of their work has been forgotten. An exception is probably the work of Elles and Wood, who are still both cited in the graptolite literature.

However, these forgotten women are not confined to a geological area or a discipline. They worked across the whole area of geology, and many worked overseas for a period of time, as well as travelling and collecting overseas. But further research work is needed on these aspects of women's role in the development of geology. We need to look further at the relationship between different people and the scholarly networks that developed.

There are many more women working in the earth sciences whose stories have not been told. When producing the book *The Role of Women in the History of Geology*, I tried hard to find authors for Janet Watson, Doris Reynolds and Eleanor Reid. Those women's stories still need to be told in detail. Perhaps I will have enough time when I retire to do this, or perhaps we need a second volume of the roles women played in the development of the earth sciences.

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Book review

Beale, Susan and Dodd, Mervyn (eds) 2008 *Exploring Lakeland — Rocks and Landscapes*. Kendal: The Cumberland Geological Society (ISBN 978 0 955845 3; paperback, 163pp; £9.50

This field guide is a very welcome addition to the Cumberland Geological Society's previous guide, Lakeland Rocks and Landscape (1982), which it compliments.

It is clearly written in language accessible to the general public, but contains sufficient comprehensive geological details to enable the serious student or informed amateur to visit and understand the localities featured.

A simplified, coloured geological map of the Lake District and stratigraphical table is followed by the introductory chapter that sets the geological scene and uses clear, coloured diagrams to illustrate the recent theories of plate tectonics that are so relevant to Cumbrian geology.

Excursions to 17 Lakeland localities are featured. Each has a clearly defined purpose followed by practical details of the route, maps, parking, refreshment, toilets etc.

Each chapter includes a coloured geological map of the area with topographical features and locations numbers superimposed. The geological setting is described, followed by excursion details and an itemised itinerary. The grid reference of each location is given, and there are many beautiful colour photographs of the superb landscapes, as well as line drawings to explain particular features.

The comprehensive glossary at the end will enable the general user to understand the necessary (highlighted) technical terms in the text, and there is a good index for fining particular locations. Details of local museums and websites will also prove useful to those planning a visit.

My only negative thoughts are that the Arial font is not as easy to read as a type face with serifs, and that glossy paper may not do so well in the rain.

Reviewing this book has enabled me revisit 'past scenes of delight' from my armchair. I cannot walk up Carrock Fell anymore and will never go up to High Cup Nick again, but some of the gentler outings will certainly be achievable — Wasdale Head and Tarn Hows beckon! I shall be getting my own copy any day now!

— Mary Howie BA (OU Hons) OUGS MGA

Marie Stopes — palaeobotanist

Professor Bill Chaloner (Royal Holloway, University of London)

Marie Stopes has been justifiably described as one of the most remarkable women of the 20th Century. That accolade was not, of course, based on her palaeobotanical work, but rather on everything that went with the publication of her most famous book, *Married Love* (Stopes 1918), and everything that ensued from it, with the resulting combination of fame and notoriety. Just to set the scene in time, Marie Stopes was born in 1880 and died in 1958, just 50 years ago this year [2008]. She started her academic career as a palaeobotanist and coal geologist, but later moved on to become a world-renowned pioneer in defending women's rights in marriage, and in advocating the acceptance and the widespread adoption of contraception. Indeed she set up the first birth control clinic in Britain, in Holloway in North London. That phrase 'women's rights in marriage', is one of hers; it is rather a coy version of what was in effect claiming that women should enjoy sex as much as men do, and that it should not necessarily involve pregnancy. Although she never used quite such blunt phraseology, that idea was of course a very heretical view in her time. It is interesting that in 1935 a group of American academics was asked to list the 25 most influential books published in the previous 50 years (Rayner 1991). Stopes' *Married Love* scored only slightly behind Karl Marx's *Das Kapital*, and scored ahead of Albert Einstein's *The Meaning of Relativity* and, indeed, also ahead of Adolf Hitler's *Mein Kampf*. With that in mind, we can move on to look at her contribution to the study of palaeobotany (Fig. 1).

My first meeting with Marie Stopes

Marie's father, Henry Stopes, was an amateur (I use that word guardedly), but very able, archaeologist. The Henry Stopes Medal was established under the aegis of the Geologists' Association to commemorate his name, and to be awarded in recognition of significant achievement in the field of archaeology. The medallist also presented a lecture carrying the Stopes name. It was as a result of the Stopes Lecture (which was actually presented in the rooms of the Geological Society) in 1952, that I came to meet Marie Stopes, and I treasure dearly the contact with her that ensued. I was a post-graduate student of Reading University at the time and I had just embarked on research on Carboniferous plants for my PhD. The Stopes Lecture that year was given by Kenneth Oakley, who played a major role is exposing the Piltdown Skull hoax.

We were all gathered in the library of the Geological Society, having tea before the lecture, as was then the custom (and happily still is). I was with Bill Croft, a palaeobotanist in the Natural History Museum, chatting palaeobotanically with him, and suddenly there was a stir by the door of the library, and a figure strode in. This was of course Marie Stopes, dressed, as they said in those days, 'to the nines'. She had on a fantastic hat, with a lot of floral decoration, a mass of jewellery, as was her wont, and she seemed more appropriately dressed for the Royal Enclosure at Ascot rather than for the Geological Society meeting rooms.

Her arrival caused quite a stir, and there was a kind of hush in that corner of the library; Bill Croft said, "my goodness, that's Marie Stopes — you must come and meet her, because you know she was a palaeobotanist early in her career." I said, "Oh no, no, no, don't bother her", but he grabbed me and took me across and said, "Dr Stopes, you must meet Bill Chaloner — he has just started research in Carboniferous palaeobotany." She turned to us and said, at the top of her voice, "Ah, dear boy, palaeobotany was my first love!"

This of course turned heads in the library. I wished to be swallowed up by the floor, in the traditional manner. But despite that start, we kept in touch over the ensuing years, until she died in 1958. I eagerly sent her my first offprint on a Carboniferous fossil spore, and she very kindly sent me back some of her early offprints of the pre-1920s, slightly chewed by rats, for she stored her palaeobotanical papers in a garage in her home, then near Leatherhead.

Figure 1 Marie Stopes (1880–1958).

The discovery of the seed ferns

Now for a quick glance at Marie Stopes' early career.

She went to North London Collegiate College and then applied to, and was accepted by, University College London. They had only been taking women students for a relatively short time in that period, just before the turn of the century (*see Burek, this volume, page 18*). She was admitted, to read Botany with Zoology and Chemistry. At the end of her first year she did brilliantly in Botany, and got a gold medal (I don't think they give gold medals for first-year students any more!), but she did not do so well in Zoology or Chemistry.

Then the interesting development ensued that she wanted to switch into Geology, in which she was already getting interested, so she went to Birkbeck College and registered there to do a year of Geology. UC did not officially approve of this move, as they did not allow a student to do courses in different colleges of London University at the same time. However, this kind of restriction did not deter Marie Stopes — she did not worry too much about the regulations of such bodies — and she secretly registered in Birkbeck College to do her Geology as a night course. (I am sure that if the OU had existed at that time she would have eagerly registered with it instead!) But Birkbeck was available to her, so she did Geology there at night and Botany and Chemistry by day in University College.

At the end of that second year, in 1902, she graduated at University College with a First in Botany and a Third in Geology.

OUGS Journal 29 (2) Symposium Edition 2008, 26–30
© OUGS ISSN 0143-9472

Soon after she graduated, Professor Oliver, who was head of Botany at University College, employed her as a graduate research assistant, funded by his own research grant from the Royal Society. He had encouraged her greatly in her botanical work, and her interests were already moving into palaeobotany.

She started to work with Oliver on a group of plants that were later to become important in the development of palaeobotany. Palaeobotany has always had to grapple with the fact that plants, unlike most invertebrate animals, tend to break up before they become fossilised, so you get separately fossilized leaves and stems and seeds, all of which, upon discovery, are given their own separate names, and there is usually very little knowledge of which parts belong together. In Carboniferous rocks there is an abundance of fern-like leaves, which had generally been assumed to be, indeed, ferns — and it became common at that time to refer to the Carboniferous as an 'age of ferns'. But by the turn of the century, several palaeobotanists had become aware that many of these fern-like leaves never had sporangia on them, as living ferns do. This seemed a little odd, and already suspicions were arising that they were perhaps not all just ferns.

This was a problem that was intriguing Professor Oliver at University College, and his colleague, D. H. Scott, who was actually based at the Royal Botanic Gardens, Kew. Oliver put Marie Stopes, to work on these leaves and a number of the other organs that occurred with them in coal-balls. These calcareous nodules, which were being encountered in significant numbers in the British Lower Coal Measures at that time, formed within the coal before it underwent significant compression, giving 3-D preservation ('permineralization') of plants. The study of these beautifully preserved fossil plants in coal-balls became a major feature of palaeobotany in the first half of that last century.

So Marie Stopes embarked on a study of thin sections of coal-balls, looking at the foliage, the seeds and the stems of some of these Carboniferous plants. Marie was much involved in searching for the minute glandular hairs, which occurred on the cupule that contained the seeds of these plants, and on one type of leaf, one type of stem, and on no other plants in the coal-balls. That was indeed the very core of the evidence for piecing together a plant with fern-like leaves, but which bore seeds, and had stems that were structurally rather like those of a cycad — a seed plant. This was the basis of the concept of the 'seed ferns' (Oliver and Scott 1904) based on the reassembly of the plant that had stems of the genus *Lyginopteris*, foliage of the genus *Sphenopteris*, and the seeds called *Lagenostoma*. Oliver and Scott acknowledged Stopes' contribution to their work with the phrase: "the authors are indebted to Miss M. C. Stopes for the detection of this vital piece of evidence". Scott's drawing of one of those seeds in its cupule, covered with the glandular hairs, is shown in Figure 2. The discovery of this extinct group of plants had particular significance in being seen as a 'missing link' between the ferns ('cryptogams') and the seed plants ('phanerogams'). But by the time the Oliver and Scott paper was published, Marie had moved on to other things.

Figure 2 A drawing, probably by F. W. Oliver, of the cupule in which the seed-fern seed called Lagenostoma *was borne; the glandular hairs, on which Marie Stopes worked, can be seen on the outer surface of the cupule.*

The 'first flower'

Marie Stopes left University College with a scholarship awarded on the strength of her botany results, to spend a year in Munich University, to work with an eminent botanist, Professor K. Goebel. He was a leading plant morphologist at that time, and she worked for a year there on the reproduction of cycads. She wrote a thesis in German and defended it, also in German, in a two-hour *Viva*, and in 1904 was awarded a PhD, the first woman to get a doctorate in Munich University. She then returned to Britain, got a job in Manchester University, and started work there as a research palaeobotanist. Figure 3, showing Marie in her laboratory studying a thin section, probably of a coal-ball, must have been taken at about this time.

Something else important happened in Munich: she met a Japanese botanist named Kenjiro Fujii, who was working with Goebel, and to whom she became very attached. Nevertheless, when she obtained her doctorate she came back to Britain and took that lectureship at Manchester. Later, Fujii came to Manchester to do research there for a while, and then returned to Japan.

By this time Marie Stopes had become interested in another great problem in palaeobotany, namely the origin of the flowering plants, the angiosperms. For the 200,000 million years between the first appearance of seeds at the end of the Devonian, and the middle Cretaceous, seed plants used wind as the mechanism to transfer their pollen from the parent plant to the ovule, which then developed into a seed. This anemophily (wind pollination) is the process used by all conifers today. Indeed, virtually all living gymnosperms are wind pollinated.

Figure 3 A photograph of Marie Stopes at her laboratory bench, studying a thin section, of coal-ball plants. This was probably taken about 1904–5. (I am very grateful to Harry Stopes-Roe for making this photo of his mother available to me, and for permission to publish it.)

Many flowering plants, on the other hand, do things differently. They appeared, seemingly rather abruptly, in the mid-Cretaceous, spread very rapidly; and quickly diversified by exploiting an entirely new technique for getting their pollen around. They had learnt [i.e. developed features] to attract insects (and in fact a whole range of other animals — anything small that could move seems to have appealed to them!), 'advertising' for such pollen carriers with scent and coloured petals. The pollinator, in return, was rewarded by the opportunity to eat the very nutritious pollen. Most insects are messy eaters and spread the pollen around in the process. Later in their evolution, flowers were to reward the pollinating insect with nectar.

This use of animals as 'pollination vectors' was one of the key achievement of the flowering plants — biotic pollination. It gave them an enormously powerful tool for successful sexual reproduction without wasting vast amounts of pollen to achieve it. The dramatic nature of that expansion of the angiosperms through the Cretaceous is the best-documented 'evolutionary explosion' in the entire history of plant life on land. But it is interesting to note that one or two major groups — the grasses and the catkin-bearing trees — reverted to wind pollination, where their ecological setting made that a more effective reproductive strategy.

Although the details of the angiosperm 'explosion' were not known in detail in Charles Darwin's time, the general picture of the fossil record of their early history was already established, and the rapidity of their spread and diversity, and swift achievement of ecological dominance, seemed in conflict with Darwin's concept of evolution by slow and gradual change. In 1879. Darwin wrote an oft-quoted letter to J. D. Hooker, who was then director of the Royal Botanic Gardens, Kew, in which he discussed the origin of flowering plants and remarked that it was "an abominable mystery".

Well, that was the setting in which Marie Stopes got intrigued with the question of the origin of the flowering plants. She was anxious to take up the challenge of what and when was the 'first flower'? The earliest angiosperm fossil leaves and wood specimens had been reported from the Cretaceous Period of Europe. Marie Stopes became aware of a report from the Japanese island of Hokkaido of some siliceous nodules (rather like coal-balls, but formed of silica rather than of calcium carbonate), of Cretaceous age, reported to contain plant material. This evidence led Marie to write to Fujii, now back in Japan, to send her one of these nodules.

When this material arrived in Britain, she described in her diary how she cut it open and the very first thing she saw was an angiosperm. We do not know quite what it was that she saw, but she was confident in claiming that it was an angiosperm, and she used that identification as the basis for a grant application to the Royal Society to investigate more of this material. It is greatly to the Royal Society's credit that its grant board awarded Stopes the funds to go to Japan, where she duly spent a year engaged in a characteristically wide range of activities, from geology to attending 'No' drama productions. For the Japanese, this immense energy and vigorous pursuit of her goals, including going down a coal mine, was, to put it mildly, unusual and rather shocking for a woman. It is clear that Marie enjoyed generating this sort of image, as she described later in a book entitled *A Journal from Japan* (Stopes 1910b)

Once she arrived in Japan, Marie went up to Hokkaido and collected more nodules, sectioned many of them, and finally hit on a cross-section of an angiosperm ovary — her 'first flower', which she was later to describe in a paper with Fujii as *Cretovarium*, (Fig. 4) (Stopes and Fujii 1910). The authors accepted that there had been other records of fossil flowers as 'compression' fossils, but reported that *Cretovarium* was "the first flower to be found in petrified material". This is indeed the female part of a flower, an angiosperm ovary with three cavities (loculi) with evidence of two rows of seeds in each — a typical monocotyledonous lily-like flower. Although subsequent work has revealed better preserved Cretaceous fossil flowers, *Cretovarium* was in its day a great discovery. Its identity as a Cretaceous flower was widely accepted and its status has never been challenged.

Through all this palaeobotanical excitement Marie's relationship with Fujii faltered, and at the end of her year in Japan she returned to Manchester.

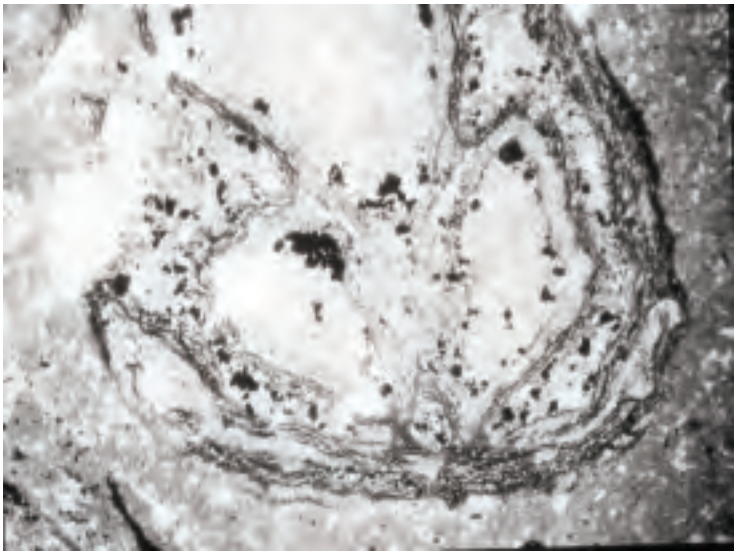

Figure 4 Marie Stopes' 'first flower': Cretovarium japonicum — *an oblique transverse section of the ovary with its three loculi, from the Cretaceous of Hokkaido, Japan (photographed by the author, from a specimen in the Natural History Museum).*

Stopes, Captain Scott and *Glossopteris*

During her time as a lecturer in Manchester, Marie published what can fairly be described as the first 'popular' textbook of palaeobotany — *Ancient Plants* (Stopes 1910a). I read it when I was an undergraduate and was very intrigued by it, and I can honestly say that it gave me an enthusiasm for palaeobotany more than anything else that I read.

In this book she mentions the Permian fossil plant, known at that time only as leaves, called *Glossopteris* (Fig. 5, *opposite*). This is a very distinctive kind of leaf: it has net-venation (the veins in the leaf link up to form a network), as in flowering plants, but it is not a flowering plant at all — we now know its reproductive structures, and it is a gymnosperm. In *Ancient Plants*, Marie writes that *Glossopteris* and associated genera "are characteristic of the Permo-Carboniferous period in the regions of the Southern Hemisphere now known by the names of Australia, South Africa and South America, and in India. These regions at that date formed what is called by geologists 'Gondwanaland'. In the rocks below those containing the plants there is evidence of glacial conditions" (Stopes 1910a, 173). In that enumeration of the components of Gondwanaland there is, significantly, no mention of Antarctica. But by that time, although Shackleton had already reported the presence of coal in Antarctica, *Glossopteris* was not yet known from that continent.

Now, Robert Falcon Scott — Captain Scott ('Scott of the Antarctic') — came to Manchester in 1906 on a lecturing tour. He was seeking support for his planned Antarctic expedition, and he gave a lecture in Manchester University. As reported by Keith Briant in his biography of Marie Stopes (Briant 1962) there was a dinner after the lecture, followed by a dance, and inevitably Marie Stopes danced with Scott. Marie recorded in her diary that she tried to persuade him to let her go with him to Antarctica to look for fossil plants there, and she suggested that he should bring his wife along as well! Needless to say, Scott was not keen on the idea at all; he said in effect that this was out of the question; but if she had some special type of fossils in mind that he ought to be looking for, and if she could show them to him, he would see if he could find them for her. Sadly, we don't know what Marie Stopes had in mind — but her awareness of *Glossopteris* as a very characteristic Gondwanan plant leads one to speculate that this was the plant that she felt might have been present in the Permian coal-bearing rocks of Antarctica, as it is in the three other Southern Hemisphere continents. But what we do know is that the following day Scott visited Marie in the university, and that she showed him some fossil plants. Did she show him *Glossopteris*, or did she show him something quite different?

Scott's party did indeed collect a considerable number of geological specimens on their ill-fated trek to the South Pole in 1912. This material, which was clearly an added burden to them on their man-handled sledge, was found with their dead bodies at their final camp site. They had found *Glossopteris* leaves in rocks exposed on the Beardmore Glacier, only 300 miles from the pole. It is recorded in their field notes that the leaves were similar to those of beech, but it was not until those specimens came back to Britain and the Cambridge palaeobotanist A. C. Seward examined them, that it became evident that Scott's party had indeed found *Glossopteris* in Antarctica. These specimens are now in the Natural History Museum, London; but, sadly, Scott's party were unaware that the specimens they were carrying under such desperate circumstances were that crucial missing piece to the jigsaw puzzle of Gondwanaland. The occurrence of *Glossopteris* in all the now-separated southern continents and India was invoked by Wegener, and by later supporters of 'continental drift', as one of the strongest pieces of palaeontological evidence supporting the idea of the reassembly of Gondwanaland. It is a pity that we shall never know what plant fossils Marie Stopes showed to Scott in Manchester back in 1906!

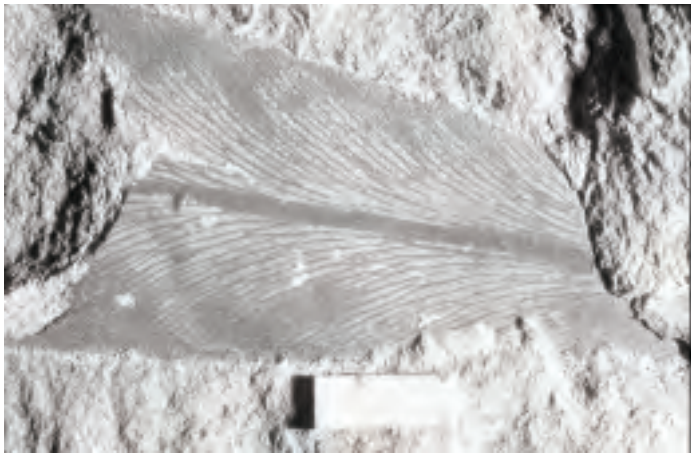

Figure 5 Glossopteris sp. *from the Permian of South Africa. This genus of leaves, with their very characteristic pattern of net venation, occurs in all the major southern continents, which formed the ancient continent of Gondwana. Marie Stopes is thought to have shown similar material to Captain Scott when he visited Manchester in 1906, prior to his ill-fated expedition to the South Pole, in the course of which his party found the first specimens of this genus in Antarctica.*

Stopes and the constitution of coal

I offer only one more item in the record of Marie Stopes' contributions to palaeobotany — one that many would regard as by far the most important. This is her work on the composition of bituminous coal and the terminology of its components. At that time, before the First World War, coal was the life-blood of the world. All merchant ships, and more important perhaps, all the battleships, ran on coal, as did much of the heavy industry. With the onset of the First World War, coal became absolutely vital for economic and military survival. It was in this context that in 1916 Marie was invited to join R. V. Wheeler, who had been placed in charge of a government-funded laboratory to investigate the characteristics of coal. The government, in the midst of war, had realised the importance of a scientific understanding of the nature of coal and of maximising its efficient exploitation as a fuel. Wheeler very sensibly approached Marie because of her publications on Carboniferous plants and coal-balls, and invited her to join him. They embarked on a serious study of the components of bituminous coal and on their role in determining its characteristics as a fuel. This was to be her last excursion into palaeobotany before *Married Love*, and all that ensued from its publication, took over her life.

In those days coal was studied under the microscope in thin section, as with all other rock types; and cutting thin sections of coal is a highly skilled operation. (It is much easier to cut a thin section of granite or limestone!). It was so soft and friable that the standard procedure was to embed it in shellac or some similar embedding medium; even then, to successfully cut and polish a transparent section of such very opaque material was a skilled and delicate operation. Fortunately, Marie did not have to cut her own sections, but had very competent technical support doing it for her. Figure 6 shows a typical British Carboniferous coal section prepared using that technique, as seen by transmitted light microscopy.

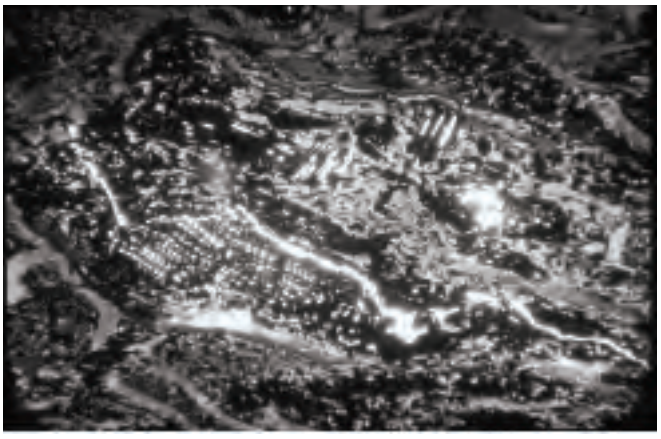

Figure 6 A thin section of British Carboniferous coal, showing a fragment of charcoal in which the original plant cells can be seen as minute cavities in an opaque, black background. The cavities have remained open, despite massive compression of the coal matrix. This is the coal maceral to which Marie Stopes applied the label of fusain (based on the French term for charcoal) although she denied the fire-origin of that coal component, which is now generally accepted.

Stopes' and Wheeler's first important contribution from this joint research was their paper 'On the constitution of coal', published by the Department of Scientific and Industrial Research (Stopes and Wheeler 1918) and in the following year Marie published a paper under her name alone: 'The four visible ingredients in banded bituminous coal' (Stopes 1919). In this paper she initiated the basic terminology of coal constituents: durain, vitrain, clarain and fusain. These four components she christened 'macerals' — the equivalent of minerals in a hard rock.

In the ensuing years, there was considerable debate over her terminology, because a group of American workers had a different way of interpreting coal formation and the role of its plant-based components. But ultimately the Stopes terms came to be adopted, with minor modifications, and have remained the basic language of coal to the present day.

There is just one feature of Marie Stopes' coal terminology that I must amiably call to question. She very appropriately chose the French name for charcoal — fusain — as the label for that very charcoal-like component of bituminous coal, which is traditionally said to give coal its dusty, 'dirty' character. You can see some fusain near the centre of Figure 6: black and opaque, but with the original porous, cellular structure of the wood still clearly evident. As is characteristic of charcoal, with its extraordinary rigidity, the cell cavities are held open, despite the enormous compression that the coal matrix has undergone. Yet, oddly, Marie always denied the possibility that the fusain in coal was in fact charcoal: plant material, usually wood, that has been altered by the process of pyrolysis — the result of exposure to the high temperature of a forest fire. She believed that there could not have been fire in those wet swamp forests, and that somehow this manifestly charcoal-like material, 'fusain', had formed by some process other than fire.

We now know that this simply is not the case. In the Florida swamp-cypress forests of the Everglades there are fires from time to time, usually following only quite short periods of drought. Figure 7 shows an area of such *Taxodium* woodland in southern Florida, recovering after just such a burn. The fire origin of fusain has since been amply documented (see, for example, Scott 2000).

*Figure 7 An area of swamp-cypress (*Taxodium*) woodland in southern Florida, recovering after a wildfire burn. This illustrates the occurrence of fire in a swamp environment, which helps to explain the presence of charcoal in the Carboniferous coals formed in a comparable swamp environment.*

Marie Stopes was right in her choice of name for that component of coal, but not in her interpretation of its origin.

I must record as a closing note that in the Earth Sciences Department of this College, Royal Holloway, research is in progress derived from Marie Stopes pioneer work in coal petrography. Professor Andrew Scott is carrying out government/industry-funded research on the composition (and particularly the fusain component) of the Russian coal that we are now importing into Britain in considerable quantities for industrial use. This Permian coal has significantly different fusain content from that of most of our Carboniferous coals and it is the nature of its fusain content that appears to be an important factor in predicting a coal's combustion behaviour, which differs from batch to batch. This research, like that of Marie Stopes, is fundamental to the most economic use of this important and irreplaceable source of energy.

Conclusion

As we have noted, palaeobotany was for Marie Stopes 'her first love'. But much more than this, as Professor Henry Andrews remarks in his history of palaeobotany (Andrews 1980), Marie Stopes "was the first woman to contribute significantly to the progress of fossil botany and one who also benefited humanity in general." This latter attribute makes her, I believe, unique in the history of palaeobotany.

Acknowledgements

I must record my grateful thanks to Tracy Atkinson who miraculously turned the recorded tape of my rather garbled presentation to the Open University Geological Society meeting at Royal Holloway, into a typescript. I appreciate enormously the patience and dedication that that must have involved! I also thank Dr Howard Falcon-Lang for reading an earlier version of this manuscript, and correcting some of the details of Marie Stopes time in University College, and Dr Harry Stopes Roe for permission to use the photo of his mother (Fig. 3). Finally, I thank Dr David M. Jones most warmly for his many helpful suggestions for improving the structure of this paper.

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Fear, reverence, entrapment and enlightenment: selected aspects of the story of meteoritics up to 1864

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Introduction

Soon after arriving at National Museums Liverpool (National Museums and Galleries on Merseyside as it was then known) the author was provided with the chance to develop a meteorite collection as part of the overall collecting policy of the Earth and Physical Sciences Department. This serendipitous opportunity has created the rare privilege of being able to curate extra-terrestrial materials as part of the Petrology and Mineralogy collection. Serendipity, careful curation and the creation of catalogues are fundamental means by which meteorites are collected, preserved and documented. As a result, it is fortunate that most of the historically important meteorites are held within institutional collections, and they have become objects, certainly since the latter part of the 19th century, of both institutional and national pride. Meteorites, as well as being objects of intense study involving techniques at the leading edge of 21st-century science, also provide a link with the historic past of folklore, collectors, curation, personalities and a growing awareness of a wider world-view than was prevalent during the middle of the 18th century and earlier periods in history.

The Peekskill fall

Sixteen years ago an event took place across northeastern America that alerted thousands of people to the transient nature of meteorite falls. On 9 October 1992 an exceedingly bright fireball, on a shallow angle of trajectory, lit up the sky and attained a particular place in meteoritic history by becoming one of the best known meteoritic events of modern times. First of all, it was exceedingly bright: magnitude -13, brighter than the full Moon. It was witnessed by thousands of people and at least 16 video recordings of its passage were made. These indicate that the meteoroid body fragmented into some 70 fragments about 41.5km above the Earth's surface while travelling at an estimated 14.7km/s (Beech *et al.* 1995). More importantly, its track was measured from West Virginia to the fall site.

The meteoroid covered some 700–800km of ground track in about 40 seconds before hitting the back of Michelle Napp's car in Peekskill, New York. At the time Ms Knapp, a student, was alerted by a loud bang in the driveway of her suburban home. She failed to notice the meteorite at first. What she noticed was that something had gone right through the trunk of the car and caused a lot of damage. Her immediate thought was vandalism, so she called the police out, who filed a report for criminal mischief. Fortunately for meteoritics, one of the policemen noticed that the petrol tank had been punctured and alerted the fire department. The culprit was eventually found under the car and impounded by the police before being returned it to its rightful owner.

Now this is a very rare event — how often do you get cars hit by meteorites? The car plus meteorite was bought by the meteorite dealer R. A. Langheinrich, who has since shown the damaged red Malibu coupe around the world. The meteorite weighed 12.37kg and was classified as an H6 chondrite, one of the more common types of stony meteorite. The car and meteorite are kept together as a display showing the meteorite in position after impact. The large number of reliable eyewitness statements and ample video footage enabled the meteoroid's orbital path to be determined, the fourth time in history this has been possible.

Meteorites in the classical world

From the well documented Peekskill fall it is necessary to regress some two millennia in order to examine the recorded beginnings of meteoritics. We owe a lot of our early knowledge to that great observer and compiler of the natural and physical world, Pliny the Elder (Gaius Plinius Secundus, *c.* AD 23–79) who attempted to gather all the facts known at his time and to collate the resources and information in his *Historia Mundi Naturalis* (1469) (This is the earliest recorded printed edition in the western World and not the date of writing; there are earlier illuminated handwritten manuscript editions.)

One of the entries concerned the prediction by Anaxagoras of Clazomenae (*c.* 500–428 BC) of the fall of a rock from the Sun. Why the Sun? The Sun and meteorites in the early classical world had quite a strong connection. In 464 BC, a brown stone about the size of two millstones plunged to Earth at the Aegos Potomas district of Thrace (northern shore of the Hellespont [now the Dardanelles]). Diogenese of Apollonia (*c.* 460 BC) heard about the stone and surmised that it had a cosmic origin, writing, "meteors are invisible stars that die out, like the fiery stone that fell to Earth near the Aegos Potamos."

This prophetic statement appeared to be on the right track. Unfortunately for history, Diogenes wrote at the time that Aristotlian teachings were prevalent in the classical world, particularly his Meteorologica, written *c.* 340 BC, which still exerted an influence on thought until the scientific revolution of the 16th and 17th centuries. These teachings were later clouded by some of the ideas the English natural philosopher and mathematician Isaac Newton (1643–1727), put forward in his *Philosophiae Naturalis Principia Mathematica*, which did not allow for the existence of small bodies beyond the Moon and that space was in effect empty of solid matter, perhaps this was a reference back to Aristotle's concept of the quintessence or ether.

Diogenese's statement was overlooked and it has taken more than 200 years of research for his idea to be accepted. The reason that 'stones from the sky' were considered to be important in ancient times can be surmised by the fact that there is a strong cultural relationship between the observance of earthly and celestial deities and natural phenomena. Across the Greco-Roman world during the period from 300 BC to AD 300 we find evidence of reverence being attributed to possible meteorites. The betyl coinage (derived from the Greek *baitylos*, meaning 'sacred stone' or 'stone fallen from heaven') and medals often depict on the obverse an *omphalos*, which is a cylindrical pedestal with an upper surface that is a hemisphere or cone-shaped. Other coins show either a stone with a bird perched on it or a cart with a stone being hauled by bullocks.

Stones are revered for different reasons, and they are not always meteorites; but in the case of the Stone of Emesa this was thought to be the earthly representation of the Sun God

OUGS Journal 29 (2) Symposium Edition 2008, 31–9
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Heliogabalus (Burke 1986). Elagabalus (*c.* 203–222), who at that time was a twelve-year-old youth and described as having 'uncommon beauty and godly qualities' was appointed high priest in charge of the Stone of Emesa at the temple. He started to design very elaborate ceremonies, which soon became famous. Elagabalus, who was rumoured to be the illegitimate son of the ill-fated emperor Caracalla, was proclaimed Emperor by the Roman troops serving in the area and given the name Marcus Aurelius Antoninus. He was recognised as Emperor by the Senate in 218 and in his triumphal entry into Rome brought the Stone of Emesa with him, proclaiming it to be an object of public worship as the terrestrial embodiment of the Sun God. The contemporary historian Herodian (*c.* 170–240) described the stone as being black and conical in form. Elegabalus abused his position of privilege, became profligate, and he was eventually assassinated by the Praetorian Guard in 222 (Burke 1986). At this point the stone disappeared from history.

The earliest witnessed fall

All meteorites from classical antiquity have been lost. The earliest witnessed fall from which a stone still exists has been proven relatively recently, and this is at Nogata-shi on the island of Kyushu, Japan. After a brilliant flash and loud explosion on the night of 19 May 861 a stone landed in the garden of the Sugo Jinja Shinto shrine. At first it was not recognised as a meteorite, although the priests preserved it as a special treasure of the shrine, never doubting that it had fallen from the sky. In 1922 the head priest sought an expert opinion and Dr Kunhiko Yamada, principal of the Chikuho Mining school, declared it to be meteoritic in origin from its irregular shape and surface features. Many years later, in 1979, the stone was examined by Professor Sadao Murayama of the Tokyo Museum of Science along with four other experts. Analysis of the 472g stone showed it to be an L6 chondrite. Its significance is that it is the earliest recorded fall where a stone still exists and we know its age by association with the box in which it is kept, which has been radiocarbon dated to within a century of the fall date compared with oral history. The match of its near contemporary box and historical record mean everything to a museum curator (Fig. 1).

Figure 1
The Nogata-shi chondrite (courtesy of Masatake Honda, Nihon University).

Ensisheim

The oldest surviving meteorite in Europe is the famous one at Ensisheim. This meteorite was observed to fall on 7 November 1492 outside the town near a peasant lad, who was working in the fields when the stone thudded into the ground fairly close to him. So we have good provenance: he had observed that it had fallen from the sky, and immediately alerted his fellow townsfolk. They rushed out and the first thing they did was hack bits off the stone. Why? Perhaps they used these fragments as talismans, good luck charms, curiosities and medicines.

(Three digressive notes: in Japan there are 54 recorded meteorite falls and finds. China is very much larger than Japan with a land mass area of 9.6 million square kilometres. With such a large land mass, equivalent to 1/15th of the World's total landmass, it could reasonably be expected that there would be a significantly greater number of meteorite falls and finds recorded and housed in institutions. The paradox is that Japan has recorded a greater number of indigenous falls than China per unit area of landmass. Perhaps part of the reason for this, apart from relative population density, may lie in cultural differences between the two countries. Whenever a meteorite is found in China it risks being lost to science by being ground up for use in pharmacopoeia, as a source of medicines. From 700 BC to AD 1930 there have been 337 meteorites documented from China.

On 4 September 1886 at Novy Urey, Russia there was a brilliant light and loud explosion when a meteorite fell to Earth near some peasants. They rushed to the fall site, whereupon some of them broke off pieces and attempted to eat them. This must have caused dental havoc as this greenish-coloured meteorite was found to contain diamonds of cosmic origin and gave its name to a new group, the ureilites.

In recent years stones from the Mbale fall in Uganda (1992) were reported to have been ground up and used as a cure for AIDS.

Stones from the sky have been revered, not just in a religious sense but also in a pharmacological sense, which may be why so many specimens have disappeared from history.)

The Ensisheim stone, via the introduction of printing, could be construed as exerting a political influence through publicity and propaganda. Its preservation was through a quirk of fate: at a time of European political instability King Maximilian (1459–1519), heir to the Holy Roman Emperor Frederick III, was on his way to fight the French, and in 1492 approached the Hapsburgh city of Ensisheim with his army. He sent for the stone and asked his advisers about its meaning. Stones falling from the sky, and other atmospheric phenomena, were normally considered portents of evil. However, his prudent advisors indicated that the stone was a sign of God's favour. Maximilian, pleased with this advice, hacked off two samples, one for himself and the other for his friend the Archduke Sigismund of Austria, and then returned the remainder of the stone to the townsfolk with instructions that it be kept chained in the parish church for posterity, as an omen of good luck and as a testament to this miraculous occurrence. Maximilian fought the French and won, much to the relief of his advisors. The chaining of meteorites was not unusual, and in France it became a quaint custom to ensure that they would not disappear as quickly as they came.

The Ensisheim fall was crucial in the early history of European meteoritics because the stone still exists (Fig. 2, *opposite*), and because Sebastien Brandt (*c.* 1458–1521), foremost satirical poet and writer of the day, was quick to capitalise on this by utilising a new empowering medium, that of print. He produced a broadsheet for distribution, which showed the stone falling from the sky, the town of Ensisheim and Maximilian observing it with good luck omens incorporated in the iconography. Accompanying German and Latin texts discuss and describe the fall of the stone, and there are verses to honour Maximilian's memory.

This was a reasonably erudite account of this particular fall. It is notable for the lack of portents of evil, harbingers of doom and bad

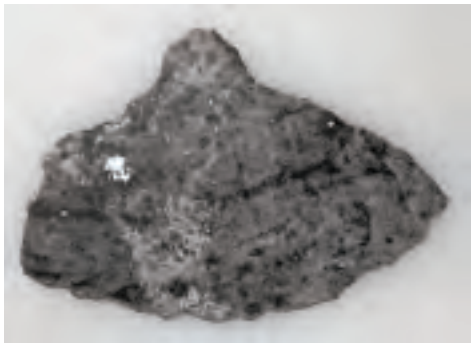

Figure 2
Slice of the Ensisheim chondrite showing its brecciated internal structure (© L.E.M.E, Muséum National d' Histoire Natural [Paris]).

omens so often portrayed in similar types of literature. However, another broadsheet, which plagiarised Brandt's sheet, gives a different interpretation: the stone is shown falling in a menacing context, the town has been enlarged and the iconography has changed. Two birds fall dead from the sky; there is a wind-face in the dark clouds; a salamander crawls away from the stone (an amphibian at the time associated with resistance from fire); a knight is looking up, and his squire has been turned into a rat-like creature. Most telling of all is an owl perched on top of a nearby chimney — in 15th-century Europe the owl was regarded as a portent of evil, rather than a symbol of wisdom (Marvin 2006).

Marvin also unearthed another image, dated 1513, of the Ensisheim fall (Fig. 3). This is a pastoral, romanticised and fanciful depiction that significantly changed the scene from the lone peasant out in the field who actually witnessed the fall: it shows two people working in the field sowing winter wheat as the meteorite descends from the sky.

Figure 3
15th-century image of the Ensisheim Fall (courtesy Susi Stöckli, Korprationsgem einde der Städt Luzern).

The artist and engraver Albrecht Dürer (1471–1528) is also important in the Ensisheim story. He was living in Basle in 1492 and may have been another eyewitness to the Ensisheim fall, for it appears that he used his own experience or that of other eyewitnesses in several ways. On the back panel of his painting of the Penitant Saint Jerome (National Portrait Gallery, London) another painting, dated between 1494–1496, has recently been discovered. It depicts boiling clouds and a brilliant fireball coming across the sky. It is probably the earliest depiction of a true image of a fireball in the history of art and in the history of meteoritics (Fig. 4).

Dürer may also have depicted the Ensisheim fall in his copper engraving *Melencholia I*, completed in 1519. The engraving shows the seated figure of 'Melancholy'. In his broadsheet on the Ensisheim fall, Brandt described the stone as falling obliquely, cast from a star like Saturn (Marvin 2006). As medieval and Renaissance writers associated Saturn with melancholy, it seems as though Dürer masterfully depicted this association in the engraving.

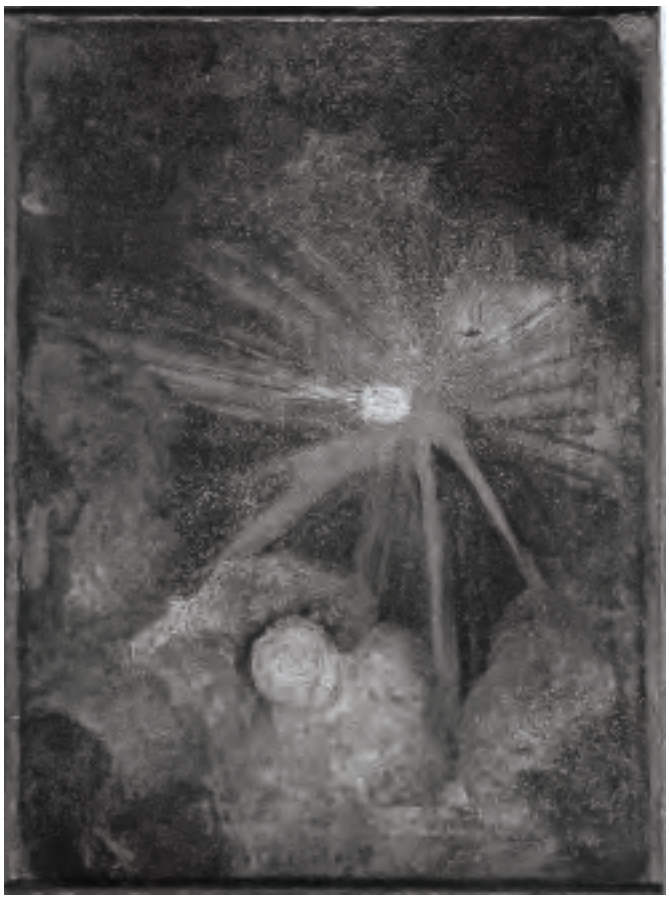

Figure 4 Dürer's painting of the Ensisheim fireball (courtesy National Portrait Gallery, London).

A close examination of the iconography shows that Dürer's engraving depicts the fall in the daytime, not at night as has been previously assumed. Earlier interpretations of the engraving have imagined the celestial body shown as a comet. However, the depiction is of a body travelling at great speed, lighting up the landscape and exploding below the arc of the rainbow with the Sun above the western horizon, the direction from which the observer views the scene, and is thus surely a depiction of a meteorite fall.

The Pallas iron

A famous 18th-century European meteorite find is the Pallas Iron, so called because Peter Simon Pallas (1741–1811) described it on his scientific travels through the Russian Empire in 1772. Pallas stopped off at the town of Krasnojarsk in Siberia and sent his aide south to conduct further exploration. The assistant stopped off at the village of Ubeisk where he spotted a large lump of rusted metal by the door of the local blacksmith, Yakov Medvedev. Closer examination showed this to be a large iron object, full of cavities, some of which were filled by a glassy yellow material.

Medvedev had come across the iron in 1749 while surveying for iron ore deposits with the mining engineer Johan Mettich on a ridge of Mount Bolshoi Emir. During the winter of 1750 Medvedev dragged the 70cm diameter mass of metal down the mountain side and across 20km of frozen and partially swampy land.

Local people venerated the iron as a gift from heaven, although Medvedev's interests were more secular: he was hoping to use the mass for forging implements. After all, it appeared to be a natural resource, so why not use it. Unfortunately, he found it to be too malleable in its natural condition, yet too brittle to work when heated, so the iron mass was left outside the workshop.

Pallas's aide obtained a specimen and showed it to Pallas, who thought it most unusual and worthy of detailed study. Despite giving an accurate description of the meteorite Pallas was non-committal about its origin. He arranged for it to be transported to the Imperial Academy in St Petersburg, a difficult journey that took more than four years because transport of such a heavy mass was dependant upon winter sledging seasons. Later, in 1825, the mineralogist Gustav Rose (1798–1873) classed all stony meteorites that are composed of iron and olivine as Pallasites. In 1980 the Russian government decided that it was time that this meteorite find was honoured and they erected a 2m diameter cast iron disc on the discovery site where Yakov Medvedev had found it, on the ridge of Mt Bolsoi Emir (Fig. 5).

Figure 5
Monument to the Pallas iron (courtesy M. A. Ivanova).

Meteorites and South America

When the Spaniards colonised South America they prospected for natural resources, in particular iron, silver and gold ores.

While travelling across Argentina in 1584 Capitán Hernán Mexia de Miraval found a large metal mass projecting from the soil, the first record of the examination of a meteorite in the Americas. Unfortunately, de Miraval's discovery was not acted upon and his record lay undiscovered, forgotten for almost 340 years. In 1774, after hearing tales from local Indians about iron falling from the sky amid raging fires, Don Bartolomé Francisco de Maguna led an expedition to locate the iron and found a large plate-like mass that became known as Mesón de Fierro. Later, in 1783, Lieutenant Rubin de Celis was despatched to re-locate the iron mass and see if it formed an economically viable deposit around which a colony could be established. He excavated around it to see if there was a continuous ore body and took 12kg of samples away for analysis. One wonders how he managed to achieve this, as nickel-iron is malleable, just as Yakov Medvedev had found, so a chisel would penetrate it without removing any sample. De Celis had the iron mass drawn and described, stating that its maximum dimension as 3.54m, and estimated its weight to be 15,000kg and of no commercial interest (Fig. 6). Samples of the meteorite were sent to the Royal Society in London and to other leading European institutions.

Although meteoritic materials were beginning to accumulate in Europe and other locations around the world, savants still failed to reach an understanding of what they were, many clinging to a hypothesis of the destruction of mountains by the volcanic fires consuming them from within. To an individual from the Age of Enlightenment a fall of a mass of iron from the sky would have been most irrational. However, the local Indians knew — they said that this mass fell from the sky amid raging fires. They were referring to folklore, passed down in oral tradition. The masses of iron that Miraval found and de Celis excavated probably fell about 4,000 years ago and it must have been an awesome sight, because the Campo del Cielo strewn field is one of the longest in the world. In 1969 the second largest iron meteorite in the world, known as the el Chaco iron, was located in this field. When extracted by the Argentine government it weighed 33 tonnes. The break up and fall of the Campo del Cielo meteoroid would have had an immense effect on the Indian population — burned in their mind, they knew these things came from the sky. However, in Europe attitudes were different.

Figure 6
Drawing of Meson de Feirro from a sketch by Don Rubin de Celis.

Chladni and the awakening of European meteoritics

Late 18th-century Europe was under the spell of the Enlightenment, with a fashion for promoting experiments in natural philosophy and rational thought. It was also the time of itinerant lecturers, who travelled Europe, often by invitation, to indulge in promoting their ideas of the world around them and the forces acting upon it, whether promoting the latest discoveries in astronomy, geognosy or natural philosophy. During this period one individual became, in later years, to be described as the father of meteoritics, though it is perhaps rather invidious to ascribe the development of the science to a single person.

Ernst Florens Friedrich Chladni (1756–1827) (Fig. 7) is primarily remembered for his work on acoustics. His entry in the National Biography describes at length his acoustical work. However, as a side mention it is noted that he wrote a pamphlet on meteorites. This 64-page book eventually turned out to be one of the most influential works in the history of meteoritics. In it he made several proposals: that meteorites and fireballs were related; that meteorites were stones that actually fell from the sky; and that they had an extra-terrestrial origin. His ideas were ridiculed. The German press considered his proposals to be nonsense. A copy of his book was sent to Sir Joseph Banks, who promptly filed it away and never read it, so it took a long time for Chladni's work to be appreciated.

Figure 7 Ernst Florens Freidrich Chladni (1756–1827).

Chladni earned his living as an itinerant lecturer, never having held a university post, despite being trained as a natural philosopher. He made tremendous developments in the science of acoustics, but unfortunately could only make his living by travelling around

Europe giving popular evening talks at various invited functions, primarily on philosophical subjects, as was the fashion of the age. Later, risking ridicule, he began to promote his ideas on meteoritics.

Chladni published his work in 1794: *Über den Ursprung der von Pallas gefundenen und anderer ihr ähnlicher Eisenmassen, und über einige damit in Verbindung stebende Naturerscheinungen (On the Origin of the Mass of iron found by Pallas and of Other Similar Ironmasses, and on a few Natural Phenomena Connected Therewith)* (Fig. 8). In it he laid down the theoretical groundwork for the new science of meteoritics. He stated that masses of ironwork and stone did fall from the sky; that incandescent fireballs are formed from frictional deceleration of solid bodies that are coming through the atmosphere; and that these solid masses originated in space. The last point is important, because at the time the prevailing view in Europe was that the solid masses were formed as exhalations of sulphurous humours within the Earth's atmosphere. There was also resistance to the work because it contradicted Aristotle's and Newton's idea that all space beyond the Moon is empty of solid material. The prevailing view was that meteorites occurred as a result of ejecta from volcanoes; from gases condensing in the lower atmosphere; or from falling cloudy lumps, which then accrete, rather like hailstones, until they dropped to the ground.

However, serendipity has always played a role in science, and despite widespread disbelief in Chladni's work, the appearance of his book was fortuitously coincident with four significant meteorite falls: Siena, Italy, June 1794; Wold Cottage, England, December 1795; Benares, India, December 1798; and Évora Monte, Portugal, February 1796. These events could not be disregarded, and savants began to take notice. By 1802 Chladni's ideas had gradually gained acceptance, and Alois Beck von Widmanstätten (1753–1849) was very keen to meet him. When they eventually met, Widmanstätten presented Chladni with a penknife and an etched slab of the Bohemian Elbogen iron meteorite found *c.* 1400, and these items are still preserved in Berlin as part of Chladni's collection — he was probably the first person to actually make a copy reference collection of meteorites as a result of following his interests.

Ueber den

Ursprung

der von Pallas gefundenen

und anderer ihr ähnlicher

Eisenmassen,

und über einige damit in Verbindung stehende

Naturerscheinungen.

von

Ernst Florens Friedrich Chladni,

Riga,

1794.

Figure 8 Title page of Chladni's book, Ironmasses*, published in 1764.*

Widmanstätten and his 'Nature Prints'

The analysis of iron meteorites took a step forward with the work of Alois Beck von Widmanstätten, a chemist and director of the Imperial Industrial Products Cabinet in Vienna. He took a sample of the Hraschina iron fall (Croatia, 1751) and etched it with nitric acid, which revealed strong criss-crossing lamellae. Widmanstätten, coming from a family of printers, thought that the etched pattern looked like a printer's plate. His curiosity piqued, he then cut and etched several irons, inked their surfaces and created what he called 'nature prints' on paper (Fig. 9), which not long afterwards began to be called Widmanstätten figures (e.g. Schreibers 1820). He was not the first to notice these patterns, however, as the English mineralogist and chemist William (Latinised to Guiglielmo) Thomson (1761–1806) had described them some years previously and produced a drawing of the 'Widmanstätten figure' that was published in the French Bibliothèque Britannique (1804) (Fig. 10). A revisionist approach to history has suggested that the Widmanstätten figures be renamed Thomson figures because of this prior publication. Nevertheless, Thomson made no significant advances in the understanding of the metallurgy of irons, while Widmanstätten did inspire others to work towards an understanding of them, although his prints did not appear in the scientific literature until 1812. Two hundred years of usage have established the name 'Widmanstätten' and it would be invidious to change it now, as it was his work and inspiration that brought study and understanding (Marvin 2006).

The Siena meteorite fall

One meteorite fall that coincided with Chladni's publication was a shower of stones fell at Cosona on the outskirts Siena on the 16

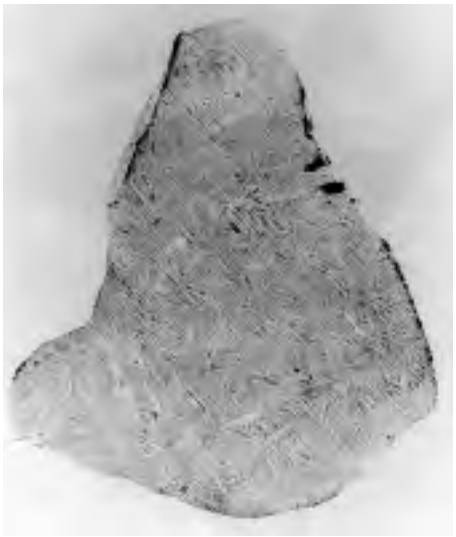

Figure 9 Widmanstätten 'nature print' of the Elbogen iron (from Schreibers 1820, pl 9).
Figure 10 Guiglielmo Thomson's figures of the Pallas iron (from Thomson, Bibliothèque Britannique 27, 1804).

June 1794. Siena was a university town with numerous savants, many of them 'natural philosophers'. A large number of people witnessed Cosona fall, many of whom were considered to be reliable, and this fall proved to be important in the subsequent history of meteoritics. First, the number of witnesses made it difficult to deny the event; second, the fall came to the attention of the university savants; and third, it also came to the attention of several English savants who were in Italy at the time.

The Abbé Ambrogio Soldani (1736–1808), Professor of Mathematics at Siena, immediately set about collecting witness' accounts, reports and stones. Within three months he had produced a book entitled *On a Shower of Stones that fell on the 16th of June at Siena* (1794) (Fig. 11). Soldani's work was important because it raised meteoritics from a collection of folktales towards serious scientific investigation. He still proposed that meteorites were formed in the Earth's atmosphere because they came out of a glowing cloud, but what had not been realised was that the cloud was the after-effects of the fireball leaving a trail across the sky. Nevertheless, this aspect of the witness' statements was not fully appreciated and was left to future observations to fully understand. Soldani himself was confused by what he believed, by what was seen and by fresh interpretations. He attempted to write a fully reliable account, but held firm to his belief that meteorites were formed in the atmosphere. This confused thinking was quite typical of the period.

Figure 11 The end plate of Ambrogio Soldani's book on the Siena Fall (courtesy Smithsonian Institution Libraries).

Still, in a sense Soldani laid some of the groundwork that helped to further the acceptance of Chladni's hypothesis, but at the same time inadvertently clouded the picture by keeping to the atmospheric origins of stones. Soldani sent some of the stones to mineralogists and other 'natural philosophers', in particular to Guigliemo Thomson in Naples. Thomson examined the specimen and conducted the first mineralogical separation of a meteorite.

A stone was also sent to Sir William Hamilton (1730–1803) via Frederick Augustus Hervey (1730–1803), Fourth Earl of Bristol and Bishop of Derry. Hamilton was envoy to the court of King Ferdinand IV in Naples, and at the time was undertaking pioneering observational volcanology — it was his observation of Vesuvius' activity and his reports to the Royal Society, and his publication of *Campi Phlegrai* (1776; arguably one of the world's most beautiful geology books) that helped to put volcanology on a firm scientific footing. At the time of the Siena fall, Vesuvius was erupting, so the prevailing view was that the stones were a consequence of the eruptions, material from the volcano being thrown up so high that it travelled 250km, to fall at Cosona.

There were two problems with this interpretation: first, the trajectory of observable stones flung from Vesuvius was too short for them to reach Siena; and second, the Vesuvian ash plume was facing in the wrong direction before the meteorite arrived. To counteract this criticism, it was stated that the volcanic plume rose during the eruption until it met wind going north, which directed it in a circular direction until it met a stormy cloud, and the ash material coagulated so that the stones then dropped on Siena. Hamilton included a paragraph on the fall in his February 1795 account to the Royal Society (Hamilton 1795), which confirmed to people that stones can indeed fall from the sky, even if Hamilton had inadvertently increased the association of such events with volcanoes.

Thomson had left Oxford prematurely, abruptly resigned from the Royal Society, and fled England in 1790 after being stripped of his degrees as a result of being censured on the charge of suspicion of practicing sodomy with a servant boy (The Oxford ruling reading "et insuper eundem expellimus, bannimus et exterminamus"). He ended up in Italy where he worked as a chemist and mineralogist, and confided to his friend George Paton that he was innocent of all charges. He claimed that he had merely been conducting an experiment in the interests of science.

Thomson, like Soldani, held on to the belief that the Cosona stones had congealed from the cloud that was observed at the time the stones fell. However, he also made reference to a friend's suggestion that the stones had escaped from a lunar volcano. This anonymous individual had noticed the observations of the German-born anglophile and astronomer William Herschel (1738–1822) a few years earlier. (And there is even a report by P. M. Terzago in 1664 asserting that a monk was killed in 1650 by a rock hurtled down from a volcano on the moon.) Herschel claimed to have seen, on three occasions, volcanic eruptions on the Moon. He was an extremely fine and talented observer, probably one of the finest not only of his day, but even up to modern times.

Did Herschel actually observe lunar volcanic eruptions? Probably not, but there is a phenomena that has been discussed for many years, called 'transient lunar phenomena' (TLP), which is thought to be outgassing from the lunar crust. These events sometimes cause a short-lived discolouration on the Moon's surface, and this may be what Herschel saw. His report thus fuelled speculation that stones falling from the sky had come from the Moon.

The German astronomer Heinrich Wilhelm Matthäus Olbers (1758–1840) even suggested this interpretation, but also noticed a flaw in the argument: that if all meteorites came from the Moon and only a minute fraction reached the Earth, the Moon should be shrinking in size because there were so many of them. In turn its orbit might be changing slightly and he could find no evidence for such change. The American astronomer Benjamin Apthorp Gould (1824–1896) also addressed this problem, and it was his detailed analysis of it that finally disproved the 'Lunar Hypothesis'.

Paradoxically, we now know that lunar meteorites are found, albeit in very small numbers.

The Wold Cottage fall

Another late 18th-century meteorite fall occurred at Wold Cottage, Yorkshire: at 3:30 p.m. on 13 December 1795 a large stone fell *c.* 30ft from the young ploughman John Shipley, on land belonging to a Captain Edward Topham (1751–1820) (Fig. 12). Topham was an eccentric playwright, pamphleteer and journalist, with a penchant for publicity. A month after the fall he retired to his Wold Cottage estate from London and immediately set about collecting witness' reports, which he had published in the *Oracle*, a local paper. To increase publicity, Topham travelled down to London with the stone and exhibited it in Piccadilly, opposite the Gloucester Coffee House, a famous meeting place of the day. In 1797 he even published a handbill (Topham 1797) of the event and set about commemorating the 'uniqueness' of the fall by erecting a monument on the site: a tall tower surrounded by trees. A much-weathered plaque on the monument reads: *On this spot, on 13 December 1795, there fell from the atmosphere an extraordinary stone: 28 inches broad, 30 inches long and weighing 56 lbs; this column in its memory was erected by Edward Topham in 1799.*

The trees are long gone but the tower remains. In 1804 Topham sold the stone to James Sowerby (1752–1822), of Sowerby's mineralogy fame. After Sowerby's death his heirs put the stone up for sale in 1835 and a subscription was raised to enable the British Museum to purchase it. Here we see the spectre of a familiar museological problem, for even in these early days museums struggled to raise money to acquire specimens, particularly where they had achieved notoriety because dealers and collectors could always outbid museums.

Figure 12
Wold Cottage Meteorite from Edward Topham's Handbill (Gentlemen's Magazine 1 July 1797, fig. 1).

First scientific chemical analysis of meteorites

In 1796 Edward King (1735–1807) produced a book entitled *Remarks Concerning Stones Said to Have Fallen from the Clouds Both in These Days and in Ancient Times*. This work, the first on meteoritics in English, listed all of the stones that were known at that time, and was published to critical acclaim in England and Europe. The book started as a serious history but the text gradually evolved through the course of its 35 pages into a form of tabloid journalism. King gave credit to Chladni for his ideas, although he did not support them, preferring the atmospheric origin of stones. However, Chladni's collected facts were considered to be deserving of much attention.

The Siena and Wold Cottage meteorites, and the description of the 1799 fall at Benares, India alerted Sir Joseph Banks (1743–1820), President of the Royal Society, that recent, well observed, accounts of stones falling from the sky required serious scientific investigation, particularly since they had a similar external appearance. He commissioned the talented young chemist Edward C. Howard (1774–1816) (Fig. 13) to conduct a

Figure 13 Edward Charles Howard (1774–1816).

chemical analysis of the two stones that Banks had been sent (from Siena and from Wold Cottage). In preparation for the task ahead Howard studied Chladni's and King's books, and managed to obtain samples from the Benares fall and a stone that fell at Tabor, Bohemia in 1753. He also obtained samples from four iron meteorites, including the Pallas iron and Mesón de Ferro mentioned earlier. To assist his investigation Howard teamed up with the French émigré mineralogist Jacques-Louis, the Comte de Bournon (1751–1825) and together they conducted the first true clinical analysis of meteorites, published 1802 (Howard, with Bournon and Williams 1802).

During the mechanical separation of the components Bournon split the material into four fractions: 'curious globules', 'martial pyrite', 'grains of malleable metal', and 'earthy matrix'. In 1863 the German mineralogist Gustav Rose (1798–1873) called these curious globules 'chondrules' (Greek for 'little grains') and the stones containing them chondrites (Fig. 14). A few years later the English geologist Henry Clifton Sorby (1826–1908) examined chondrules in thin section and declared that they looked like congealed droplets of fiery rain. Fortunately, the stones analysed were all chondrites with nickel-iron in their make-up, which Howard and Bournon realised did not occur in any analysis of terrestrial rocks, lending support to Chladni's proposition of extra-terrestrial origin. Had Howard been sent 'achondrites' (asteroidal igneous material with no nickel iron), the whole history of the understanding of meteoritics might have been much delayed.

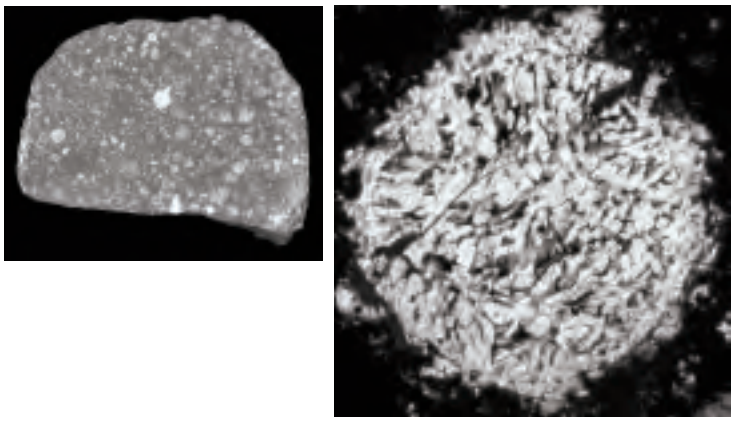

Figure 14 (left) Cut slice of the Allende (CV3) carbonaceous chondrite showing chondrules (LIV 1996.3); (right) one of the Allende chondrules in thin section (LIV 1996.52A) (both courtesy Board of Trustees, National Museums, Liverpool).

Laplace, Biot and the L'Aigle fall

The French academician Pierre-Simon de Laplace (1749–1827), a foremost mathematician of the day, was another who proposed the possible lunar volcanic origin of the stones. His ideas so inspired the young natural philosopher Jean Baptiste Biot (1774–1862) that he referred to the lunar origin of meteorites as 'Laplace's hypothesis'. However, as we have seen, Herschel had proposed this idea earlier in the 18th century.

On 26 April 1803 an event occurred that gave Biot the chance to test Laplace's ideas. A bright fireball was observed in the sky, and after three enormous explosions approximately 3,000 stones fell at L'Aigle, Normandy. Jean-Antoine Chapitale (1756–1832), Minister of the Interior, despatched Biot to investigate the fall and to collect all available information about it. Biot immediately looked at the fall site, gathered records from individuals who had witnessed it and mapped the distribution of the stones. From this evidence he declared that the stones had indeed fallen from the sky and were not of this Earth, thus corroborating Chladni's hypothesis. Further, he was able to show the accuracy of the observations of witnesses of other falls, and therefore of their credibility as well.

Towards a modern understanding

Karl Ludwig von Reichenbach (1788–1869) (Fig. 15), a German chemist and metallurgist, was one of the first professional scientists to seriously research meteorites. Using his experimental results and analyses, between 1858 and 1860 he put forward a series of ideas that represented the first coherent theory of the origins of meteoritic matter and of meteorites based on the laboratory examination of specimens. Reichenbach implied in 1858 that "A meteorite is simultaneously a cosmological, astronomical, physical, geological, chemical, mineralogical and meteorological object" (Reichenbach 1858). His analyses led him to name the three nickel-iron components that are found in iron meteorites: kamacite, taenite and plessite.

One of France's most influential geologists and mineralogists, Gabriel-Auguste Daubrée (1814–1896), was famous for his experiments in petrology (Fig. 16), and some aspects of modern experimental work in meteoritics can be said to originate from his work. He urged a wider view of petrology, saying that it should consider the formation and evolution of the Earth and of the Solar System. He had inherited a meteorite collection of 86 specimens when he was appointed to the Chair of Geology at the Museum d'Histoire Naturelle, Paris in 1861. He seized the opportunity to undertake the systematic study of meteorites and expanded the collection to become one of the foremost in the world.

Figure 15
Karl Ludwig von Reichenbach (1788–1869) (courtesy Dibner Library for the History of Science and Technology, Smithsonian Institution).

Figure 16
Gabriel-Auguste Daubrée (1814–1896).

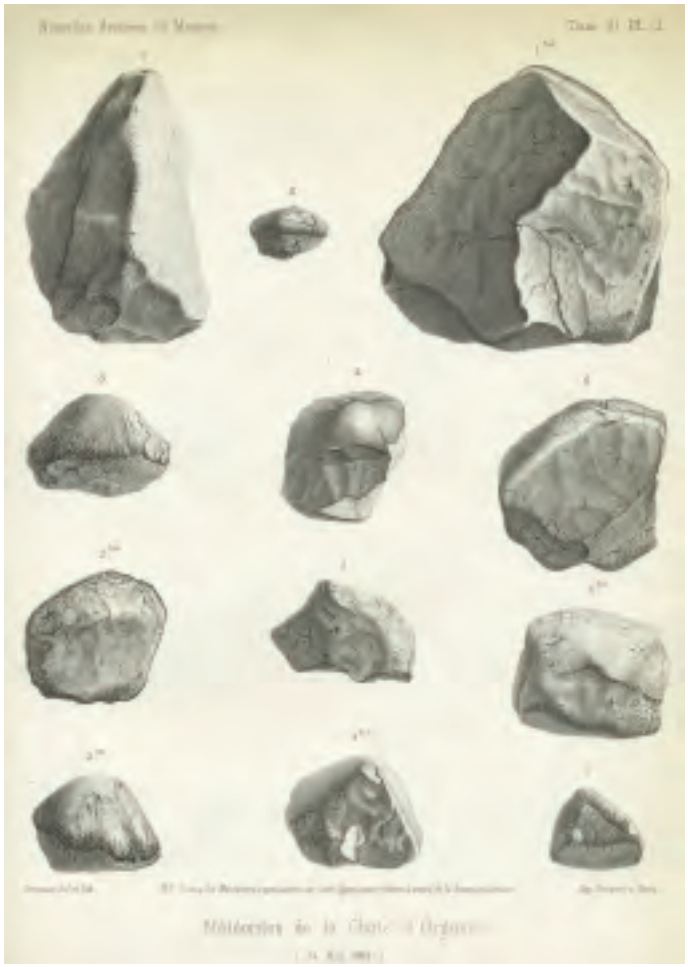

Figure 17 Drawings of the Orgueil meteorite taken from Daubrée's published description of the fall in 1867 (Archives, © MNHN).

Daubrée set to work devising a classification scheme whose nomenclature was based on the chemical and mechanical examination of meteorites. For him, the increasing meteorite collection at the museum became a means to an end, whereby he could attempt to advance research into the problems of the formation of planetary systems, research that continues today.

During Daubrée's tenure at the museum there was a meteorite fall at Orgueil, in 1864. This fall interested him in particular because the meteorites appeared to be unstable and required special curation methods to preserve them. The Orgeuil meteorite turned out to be a CI —a carbonaceous chondrite in modern classification. Daubrée (1867) described it as being similar to dull and earthy lignites (Fig. 17). This type is regarded as primitive — if they get wet they turn into clayey sludge — and in 1962 a hoax attempt was uncovered when one of the sealed jars containing the meteorite was examined closely, for the sample of Orgueil meteorite in the jar had been tampered with. An unknown individual had inserted a rush seed and other fragments of plant material into cracks in the meteorite, then carefully cemented over these with matching matrix. Perhaps the idea was to promote the existence of extra-terrestrial life in an attempt to try and discredit the French chemist and pioneering microbiologist Louis Pasteur (1822–1895), for at the time Pasteur was conducting experiments trying to debunk ideas about 'spontaneous generation' (the idea that life can spontaneously come into being inside inanimate substances). Pasteur delivered a famous lecture on the subject at the Sorbonne on 7 April 1864, which effectively debunked the concept.

Shortly after this lecture, the French analytical chemist F. S. Clöez (1817–1883) detected a substance that resembled humic acid on the meteorite and put forward the suggestion that this seemed to indicate the existence of organised substances in celestial bodies. Was the hoax a deliberate act contrived to discredit some of France's most respected scientists or merely a joke? Whatever the motive, the attempt backfired, for it was not discovered until 98 years later.

Conclusion

Daubrée's work brings us to the threshold of modern meteorite studies. The story of meteoritics is one of serendipity, enlightenment and diligence. What shines through is the determination of savants to overcome resistance to their ideas, a growing acceptance of the reality of extra-terrestrial materials and the curators and other personalities involved that make the science so fascinating.

Meteoritics grew from a folklore study, with its attendant superstition, to a place at the leading edge of 21st-century science and understanding. Diogenes prophetic statement 'quoted' (in translation) towards the beginning of this paper has been proven. His insight has been rewarded by having a class of meteorites named after him, in 1885, by the Czech mineralogist Gustav Tschermak (1836–1927).

Acknowledgements

The author wishes to acknowledge his indebtedness to Dr Ursula B. Marvin whose work on the history of meteoritics was instrumental in inspiring this contribution to the OUGS Symposium. I also wish to thank Prof. R. J. Howarth and Dr G. J. H. McCall for kindly reading through the initial script. Finally, I must acknowledge my gratitude to all the contributing authors whose work features in our book *The History of Meteoritics and Key Meteorite Collections*, G. J. H. McCall, A. J. Bowden and R. J. Howarth (eds), 2006, from which much of the material for this paper has been drawn.

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Ian Gass — our founding father

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Introduction

It gives me great pleasure to talk to you about Ian Gass, our first OUGS President and who was indeed our founding father (Fig. 1). Ian recognised that we were a scattered population, so he suggested that we hold an annual conference (Edwards 1993). In 1973, he organised the first conference at Reading, with the theme based on the very successful S100 textbook *Understanding the Earth* (Fig. 2). Ian invited each of the chapter authors to give a talk and most of them did.

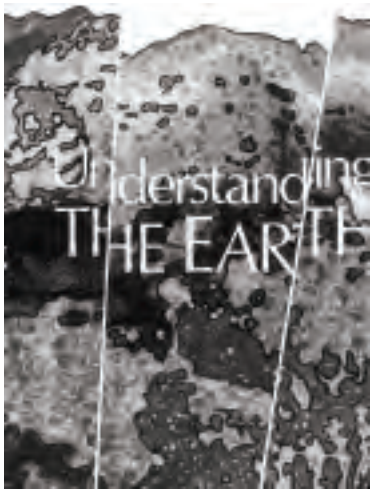

Figure 1 Ian Graham Gass 1926–1992 Professor of Earth Sciences Open University 1969-1981; Personal Chair in Earth Sciences 1981–1991; Emeritus Professor OU 1991–1992; Fellow of the Geological Society of London; Prestwich Medallist 1979; Murchison Medallist 1988; Fellow of The Royal Society 1983 (photo courtesy of The Open University).

Figure 2 Understanding the Earth*, the textbook for OU S100, sold more than 100,000 copies worldwide, and was one of the most successful Earth Science textbooks ever written.*

At this first OUGS Conference Ian brought his students to the notice of the wider geological world and members had the opportunity to mingle with the great minds in their subject, and I think we have gone on from there because these annual conferences and symposia have regularly informed us at the frontier of our science. It is perhaps interesting to note that Ian chose a couple of speakers to fill some gaps in his programme. These included Russell Coope, who, using his study of beetles, which are very fussy about their environmental temperatures, electrified the gathering by suggesting that climate change could be so rapid as to go from temperate to ice-age within 50 years. George Walker, the other speaker Ian invited, talked about huge volcanic eruptions. George used the volume of the lecture theatre, multiplied by a few million, to emphasise volcanic destructive power. We did not realise then what a visionary man Ian Gass was.

When Ian retired in 1991, all the donations went into the Ian Gass Bursary. This was to be open to OU Earth Science undergraduates and graduates to facilitate a piece of *bone fide* geological work (perhaps fieldwork or attending a conference). The reports were to be published by the OUGS in its *Journal*. I am not sure that this has been adhered to in recent years, but the fund is there for us to use (Fig. 3).

I am also not sure Ian would have cared very much whether he has a place in history; he would have been much more interested and pleased to know that the science had prospered, and that his students had done well – as indeed they have. If Ian were giving his talk, I feel confident that he would have chosen to talk about his own professor, William Quarrier Kennedy.

William Kennedy's influence

Ian, writing an obituary of Kennedy for the Geological Society, described him thus: "A slim man of no more than average stature, Kennedy was always neatly dressed, even when engaged in the roughest of field work. His office was similarly neat and tidy and indeed this orderliness and attention to detail characterized his professional life and published papers, for in his encyclopaedic memory the facts were categorized and disciplined." Then, at the end: "Bill Kennedy was always known as 'The Prof' and as 'W. Q.'. He was a truly gentle man, an intuitive geologist, a scientist of outstanding ability, and a teacher of the very highest quality." Other people have told me that to be with Kennedy at a microscope was a truly enriching experience. He described everything in simple terms but what he saw was so profound, it was totally inspiring. He would say: "Ask me anything, anything at all. If I don't know the answer, then we will work it out together." Ian placed Kennedy in the same class as Arthur Holmes and Harry Hess, and he considered that his own progress was only possible because he was able to stand upon Kennedy's shoulders (Fig. 4, *opposite*).

Table 1 shows a few of the projects that Ian did during his comparatively short life:

Table 1 Research projects during the period 1962–1992.

year	*project*
1962	led the Royal Society Expedition to Tristan da Cunha
1964	led the Royal Society Volcanological Expedition to the Red Sea
1965–78	initiated the Atlantic Volcanic Islands Project, jointly with George Walker
1975–92	Instigated and led the Oman Ophiolite Project
1979–87	led the Pan-Africa Project, jointly with Robert Shackleton

Figure 3 Ian Gass and Geoff Brown with members of the OUGS on the steps of Walton Hall 1991 for the establishment of the Ian Gass Bursary.

OUGS Journal 29 (2) Symposium Edition 2008, 40–7

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Figure 4 Professor William Quarrier Kennedy (photo reproduced with kind permission of Leeds University: from the University of Leeds Reviews *published in 1967 and 1979 © The University of Leeds).*

1979–92 led the Chromite and Platinum Group Mineralisation Project, jointly with Chris Neary and Hazel Prichard

1980–85 UK Team Leader Deep Drilling project of the Troodos Ophiolite, jointly with Fred Vine

These were major projects, and they represent only a fraction of the earth science in which Ian was involved. He was a member of many learned societies and possessed an international reputation for his work on the Committees of IAVCEI, the Royal Society, IUGG, IGCP, and latterly he sat on Royal Society Sectional Committee 5 as Chairman and was Vice President of the Royal Society 1985–6. Ian proposed and helped to organise at least six major international research conferences as well as supervising 31 research students. Selecting what to include in this paper is therefore difficult: I will first describe Ian's career before he came to the OU in October 1969, then describe some of the OU courses he devised, particularly how the Science Foundation Course was produced within 15 months, and then describe some of Ian's research activities.

Royal Navy, Army and university

Ian was born in Gateshead in 1926. He attended the Newcastle Royal Grammar School and the Huddersfield Free Grammar School of King James. He was described as a sweet child, with a lovely nature! At school, his academic achievements were described by his cousin Jimmy as 'grey', but he enjoyed and did well at sports. When the family moved to Huddersfield in 1942, Ian joined the scouts, and with his friend Colin Lawton would walk in the Dales, setting themselves targets: to do the longest walk, or the fastest walk, or the hardest walk, and they dreamed of being heroes, indicating that Ian always had a thread of ambition running through him.

In 1944, he joined the Royal Navy. His father had served in the Navy during the First World War and Jimmy was already in the Fleet Air Arm. Ian's academic ability must have been adequate, because he was sent to Oxford University to read Modern History. This was a Services short course and it was understood that the students could return to Oxford to complete their degree after the war. Ian learned to fly in the Fleet Air Arm, in Florida. He flew solo, but training stopped when the War in Europe ended, which was before he got his wings. He then joined the Army in 1945 and was posted to Penang, where he was put in charge of a landing craft tank. People might be familiar with small troop landing craft, but Ian's boat was very much more substantial. Ian was engaged in ferrying goods round the Malay Archipelago and, more gruesomely, locating and collecting bodies of allied soldiers for burial.

During this time, he gave some Shell geologists a lift in his boat, and, after chatting to them, became attracted to their work: history in the open air combined with travel — that would do for him. He was demobbed in 1946 aged 20, a Captain (Fig. 5).

Figure 5 Captain Gass, aged 20.

Under the Forces Education Training Scheme he took an Intermediate BSc at London University, in the Geology Department where Sidney Hollingworth was Professor. Ian then transferred to the four-year honours course at Leeds University, stating on his application form that he wished to become a 'survey geologist'.

Professor William Kennedy taught the first year and he enjoyed spotting talent in his students before their new friendships shaped them. He was in fact looking for 'winners', as he used to do when he went racing! Kennedy recognised in Ian a capacity for hard work, a quiet demeanour and a budding passion for the subject. Kennedy also noticed a quiet shyness — Ian was not flamboyant, and while the others were making a noise and trying to impress, Ian was getting on with the job in hand. Ian's 'northern grit', his philosophy of doing what had to be done at once and not being laid low by failure, were just the qualities required for a survey geologist. Kennedy saw this right from the start: Ian was a marked man.

Geological survey: Sudan and Cyprus

Ian obtained an Upper Second Class Degree and was appointed to the Sudan Geological Survey, flying to Khartoum in 1952. He worked in the Dunganab Area of the Red Sea Hills, north-east Sudan — a long way from anywhere (Fig. 6).

The terrain he mapped was 100% exposure. He was in charge of a team of 'boys' (as they would have been referred to then) who were fabulously resourceful. The monotonous diet of three varieties of tinned food — 'bully-beef, snapper' (a sort of fish,

Figure 6 Harsh terrain around the Gebeit Gold Mine, north-east Sudan, characteristic of Ian's mapping area.

Figure 7 Ian supplemented the monotonous diet by occasionally shooting a gazelle.

and spam) was supplemented from time to time when Ian shot gazelle (Fig. 7).

It was very hot in Sudan, and trips to Suakin on the coast, to restock supplies and relax, were much enjoyed (Fig. 8).

Figure 8 Ian, a powerful swimmer, enjoyed swimming in the Red Sea on trips to the Sudanese coast.

The Director of the Survey, Graham Andrew, had somewhat eccentric ideas concerning his staff. He considered character development to be essential and he gave them very little guidance in their preparation for several months in the field. It is not surprising therefore, that during Ian's second field season Andrew encouraged Ian and Stan Bagnell to make an expedition on their way to work in the Red Sea Hills, where they were mapping adjacent field sheets. The trek was to be in the tradition of Ray Bagnold, who in the 1920s used to spend his holidays with friends driving Ford cars to explore the Egyptian Desert. One of Bagnold's trips — checking for locusts — had finished after an eastward traverse to Wadi Halfa (Bagnold 1935). Ian and Stan planned to cross from Station 6 on the desert railway, to the Red Sea coast north of Port Sudan, a distance of 300 miles. They would load all their vehicles, equipment and teams of 'boys' on the train, go north of Khartoum to Station 6 and travel eastwards, to make the first motorised crossing of that area (Fig. 9).

Figure 9 Ready to set out on the expedition to the Red Sea Hills by way of the desert.

From his army training, Ian knew to let down the lorry tyres when they got stuck in the sand. Some days they only covered a few miles, but on other days they bowled along. Once they got to the mountains, there was no way through the north–south grain of the terrain, so they had to go up to Egypt to get round this obstacle. During the diversion they discovered some Pharaohonic gold workings, and it was obvious that those ancient Egyptians knew how to assay for gold in the field. The trip took three weeks.

When Sudan became independent Ian was retired before he had a chance to publish a memoir of the Sudan Geological Survey, so he had nothing to show for two field seasons working in very challenging conditions. Ian was dejected by this, but went to visit Leeds, where Kennedy encouraged him to write up his work for an MSc. Ian took this advice and this is probably the point at which his academic career began; certainly his interest in the Afro-Arabian Dome dates from his survey work in Sudan, even though his subsequent projects were based in Jeddah (Fig. 10).

In 1955 Ian married Mary Pearce and they spent their honeymoon on the Orient Express and cruising to Cyprus, where Ian joined the Geological Survey in August. Ian was assigned the Dhali sheet, an area to the south of Nicosia. Table 2 lists Ian's activities in Cyprus.

Table 2 Geological work in Cyprus.

year	*project*
1955	joined the Geological Survey Department
1955–7	mapped the Dhali Sheet, wrote Cyprus Geological Survey Memoir No. 4
1958	published his first academic paper
1958	carried out reconnaissance mapping of the Akamas Peninsula
1958	helped with Overseas Geological Surveys: Troodos Gravity Anomaly
1959	was retired when Cyprus became independent
1960	completed a PhD based at Leeds University, on his Cyprus Survey work

Ian joined the Geological Survey in Cyprus in 1955 and spent two years working on the Dahli Sheet, (Gass 1960). The first proper geological survey had begun in the early 1950s, and when Ian

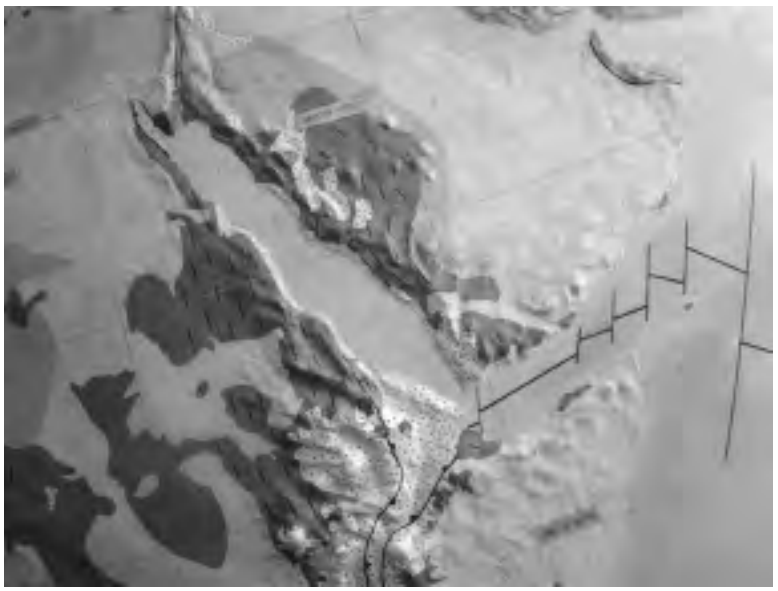

Fig.10 The area of Ian's main geological interests as seen on the Globe at Keele University: his mapping area in north-east Sudan, the Afro-Arabian Dome, Cyprus, the Red Sea and Oman.

started his mapping, the stratigraphic column was still skeletal. He began walking the clear boundary between the dark pillow lavas and the white chalk. This was a very simple approach but it has to be remembered that geological mapping was not at all easy in those times of political unrest. For example, on the evening of the day Ian and Mary arrived in Nicosia, they went out for a meal and when they returned to their hotel, it was rocked by a bomb blast.

Ian has a reputation for preferring hard rocks, but when there was work to be done, he simply worked methodically through the heap of sediments, and with the help of Dr Cockbain, the Palaeontologist, they identified and added new stratigraphic horizons throughout the monotonous chalk.

Ian noticed some distinctive dark, pillow lavas at Margi and took samples back to Leeds. When they were analysed, they were found to be ultrabasic in composition (Table 3). This was significant, because at that time it was considered impossible for lavas of ultrabasic composition to exist owing to the very high temperature that would have been required to produce a melt. Interestingly, even as this view prevailed, samples of ultrabasic volcanic rock were being dredged from the ocean floor. Again, Kennedy encouraged Ian to publish a paper, and with the help of his friend Peter Harris, Ian did so.

The style of the paper is conventional igneous petrology, but conducted on olivine phyric rocks that were undoubtedly from a melt, their pillowed structure indicative of lava emplaced under water. The analyses confirmed an ultrabasic composition. Ian's paper was pioneering in this conclusion, but not much remembered it seems.

In 1958, David Masson-Smith of the Overseas Geological Surveys undertook a geophysical investigation of the large gravity anomaly over Cyprus. Most of the local geologists helped him during his visit, advising suitable localities for the 43 recording stations. Then in 1959 Cyprus was declared independent, and all the British geologists were retired. Ted Bear, a South African, stayed and became Director of the Geological Survey Department. He was to be the crucial anchor man, because he was as keen as Ian was to pursue the Cyprus research. Kennedy had a scheme whereby Survey Geologists could obtain a PhD based on their fieldwork, provided the Director was prepared to supervise it. Frank Ingham, the Director in Cyprus prior to independence had been very happy to agree to do this, especially as Ian was the author of the Cyprus Geological Survey Department Memoir No. 4.

Redundancy, PhD and Leicester University

So when Ian was retired, he went back to Leeds to do his PhD. Ted sent him samples for analysis and Ian asked Ted for specific information from the survey records, which Ted would check or ascertain at specific localities for him. Much of the lively correspondence concerned the Sheeted Igneous Complex, a set of dykes the formation of which had caused considerable puzzlement within the Cyprus Geological Survey.

While Ian had been away in Cyprus, Kennedy, with funds from Anglo-American, had established the Research Institute of African Studies, which had attracted many bright young, mostly post-doctoral geologists. The first of these was Keith Cox. Ian, a survey geologist, a plodder, used to quiz them; with his 'northern grit' and Geordie Accent he enjoyed getting the better of these brilliant young men – in the nicest possible way! "What mechanism do you think could explain the intrusion of a series of dykes into a series of dykes?" he would ask. He went on about it so much that everyone thought he was touched; while Kennedy listened and supported him, no one came up with an explanation.

In 1960, Ian and David Masson-Smith worked together to publish the results of the Gravity Survey. Ian wrote-up the geology and David Masson-Smith wrote-up the geophysics (Gass and

Table 3 Analyses of the lavas (from Gass 1958).

Analyses

	(1)	(2)	(3)	(4)	(5)
SiO_2	43.00	42.11	42.4	44.75	51.81
TiO_2	0.18	0.23		0.49	0.57
Al_3O_3	4.64	6.59		12.52	14.50
Fe_2O_3	2.42	3.62		6.53	7.56
FeO	6.47	5.38	7.7	3.72	4.31
MnO	0.15	0.16		0.40	0.46
MgO	33.45	30.00	49.9	6.37	7.38
CaO	3.99	3.99		10.77	12.47
Na_2O	0.25	0.25		0.67	0.78
K_2O	0.05	0.17		0.13	0.15
H_2O^+	3.83	6.05		10.34	
H_2O^-	1.22	1.89		3.29	
P_3O_5	–	0.05			
Cr_2O_3	0.51	0.28			
NiO	–	0.12			
Total	100.16	100.29	100.00	99.98	99.9
S.G.	2.96	2.83	3.32		

Norms

	(1)	(2)	(3)	(4)	(5)
q	–	–			13.8
or	0.3	1.1			0.9
ab	2.3	2.3			6.6
an	12.0	17.7			35.5
$CaSiO_3$	3.7	trace			11.0
$MgSiO_3$	24.3	30.6			18.5
$FeSiO_3$	3.0	2.8			1.7
Mg_2SiO_4	44.2	35.3			–
Fe_2SiO_4	5.3	3.5			–
mt	3.7	5.7			11.0
il	0.4	0.5			1.0
ap	–	0.1			–
cr	0.8	0.4			–

column labels:

(1) Vitrophyric type of ultrabasic pillow lava, exposure to south-west of sedimentary outlier. Analyst: O. Von Knorring.(2) Holocrystalline intrusive from plug to east of sedimentary outlier. Analyst: E. Waine

(3) Olivine phenocrysts from same exposure as sp.1. Analyst: Chr. G. Soteriades.

(4) Calculated analysis of the groundmass of the vitrophyric ultrabasic type. Percentages, by weight, taken in calculating groundmass analysis were olivine 62.3, chromite 1.0, groundmass 36.7.

(5) Calculated water free analysis of the groundmass, data as in (4).

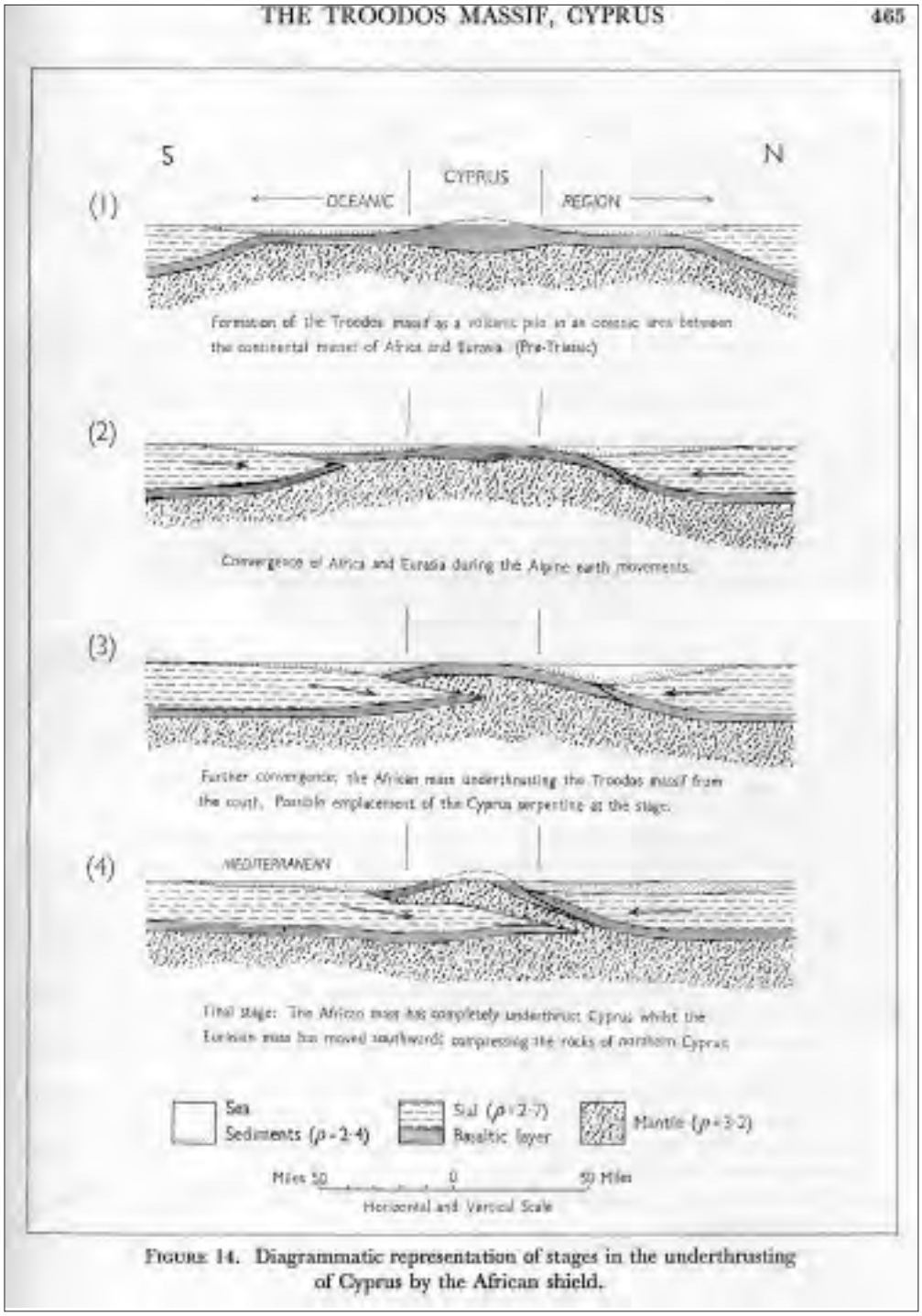

FIGURE 14. Diagrammatic representation of stages in the underthrusting of Cyprus by the African shield.

*Figure 11 Diagram from Gass and Masson-Smith 1963 suggesting progressive underthrusting of Cyprus by the African shield (I. G. Gass and D. Masson-Smith 1963 'The geology and gravity anomalies of the Troodos Massif, Cyprus'. Phil Trans Royal Soc Series A Mathematical and Physical Sciences **255**, 1060, 417–67, fig.14).*

Masson-Smith 1963). This paper caused quite a stir, because their interpretation implied that continental drift was taking place — Africa moving towards Europe (Fig. 11).

Continental drift was a contentious subject at the time. Indeed, during the Cold War the USA and the Soviet Union were united in their rejection of continental drift! Nevertheless, and possibly because the interpretations were based on geophysics, people took notice of them. Also, the sheeted igneous complex was described as a dyke swarm, and it was the scale of this Cyprus dyke swarm that aroused such interest. David and Ian suggested that east–west tension prevailed throughout the emplacement of the Troodos Massif — an outcrop 100km wide — dyke, into dyke, into dyke. Nobody had a clue what was going on. There was something similar on Hawaii but the scale was tiny in comparison to what could be seen in Cyprus.

Ian used to say much later on: "Well it was the best idea at the time"! Arthur Holmes (1965) included this work in his 'Big Red Book', the second edition of *Principles of Physical Geology*.

It is important to describe Ian's early work in Cyprus in this way, because it tended to be eclipsed once ophiolites had become an established concept. When Ian became Professor of Earth Sciences at the Open University, he showed in the one-sixth second level Geophysics S2-4 course first presented in 1973 how his work in Cyprus led the development of ideas on the formation of ophiolites. The TV and radio programmes that accompany the course are an important record of this. *[Editor's note: During the first presentation of OU Second Level Science courses, they were all half credits, as one-third and one-sixth parts. Therefore S23- Geology, plus S2-4 Geophysics, would equal one half credit S234. The one-sixth Earth Science courses were: S2-2 Geochemistry, S2-3 Environment, and S2-4.]*

Ian had decided that he wanted to join the Geological Survey because it would be a job for life. After two retirements in seven years, this plan was looking ragged, especially now that he had a family to look after, there were now two young children, Kate and Graham. Ian made a few half-hearted attempts to seek another survey post, then he took up lecturing. In this career his progress was phenomenal: in nine years he went from Assistant Lecturer, to Lecturer to Senior Lecturer to Professor at the newest university in the UK.

Some people labelled Ian ambitious, even over ambitious; but I would argue that he simply revelled in the challenges during this period of rapid scientific change and he recognised and made the most of every opportunity.

At Leicester, during 1960, Peter Sylvester-Bradley was building up his Department, but he sent his overworked lecturer John 'Mac' McWhittaker on sabbatical leave to Scandinavia and took on Ian for a year. Peter was truly an exceptional man — we should sometime have had a talk about him — and it must have been wonderful to have worked with such a person on your first job.

Ian and Mary bought a house in Leicester and it looked as though they would settle there, because Peter Sylvester-Bradley

very much wanted Ian to stay. Ian would take on anything that needed to be done, including teaching the geophysics class. However, when, a vacancy for an igneous petrologist came up at Leeds, Ian could not withstand Kennedy's determination to appoint him. Mike Le Bas was also interviewed and he was very disappointed not to get the job. "Don't worry Mike," Ian told him cheerfully, "there is a job for you at Leicester!" Mike stayed at Leicester until he retired a couple of years ago.

Leeds University and Tristan da Cunha

As soon as Ian arrived in Leeds, Kennedy, who sat on the Royal Society Volcanology Sub-Committee took him down to London. This was the start of Ian's Geopolitical career, which continued until he died in 1992. During 1961, the volcano erupted on the tiny island of Tristan da Cunha in the centre of the south Atlantic. The 300 islanders were threatened, as the volcanic plug grew 100ft (30.5m) in 24 hours, and it was 300yd (275m) from their settlement. The rugged island terrain did not give them much scope for moving elsewhere on the island. The Administrator, Peter Wheeler, organised their evacuation to one of the other islands, from which they were rescued and travelled from South Africa to England, where and their plight was the subject of national concern.

At the Royal Society, there was much interest in the study of volcanic islands because at that time it was the only way to study what was thought to be the ocean floor. It was decided to send an expedition to Tristan, and Kennedy agreed to be Joint Scientific Director with Professor Wager at Oxford. Ian was selected to lead it.

While Ian went off for several months, Mary held the fort at home with their two young children. In this regard Ian owes a great debt to Mary, who thus supported him over many years at the expense of her own career.

The expedition to Tristan da Cunha was the first systematic study of an erupting volcano. Peter Harris had visited the island in December 1961 to evaluate the activity of the volcano and to determine the safety of placing an expedition on the island (Harris and Le Maitre 1962), and the main team arrived on 29 January1962 on *SAS Transvaal*.

The Geological Team comprised Ian Gass, Roger Le Maitre, Peter Harris and Peter Baker. Together with other scientists, they made themselves comfortable in the Administrator's house. Two Tristan Islanders accompanied the Expedition, and they caught fish, especially crayfish to help feed the team — Ian cooked crayfish curry, which was described as delicious.

The two Peters went up the mountain, Roger and Ian explored by boat. They also visited every other island in the Tristan group.

After seven weeks, the Royal Navy ice-patrol vessel *HMS Protector* collected them. The sea was very rough so the helicopter was used to take them off the island (Fig. 12).

When they returned to England, Ian visited the Tristan Islanders at Calshot near Southampton and spent a lot of time telling them about their homeland. Ian felt great compassion for them, for where they were living was a dump, and they were so hungry for news of their homes. He warned them about returning too soon and advised that they wait to see the effect of the winter storms on the beaches. He explained that nobody could predict what the volcano would do. They did return the following year and I believe some of them suffered breathing difficulties.

Back to teaching at Leeds, Ian was considered very caring of his students and there are numerous anecdotes about him. John Smewing remembers Ian during his first field excursion at

Figure 12 Tristan da Cunha, the new volcano and lava, which threatened the only settlement. The crayfish canning factory, the only source of income, was inundated. Photo taken from the Royal Navy helicopter (© Crown Copyright Reserved) (Baker, Gass et al*. 1964)*

Ingleton. Ian must have noticed John's utter bewilderment with the monotonous Ordovician slates. "Oh, look there's a way-up," Ian told him cheerfully. John looked more closely and there indeed was a tiny area of cross bedding. "Wow!"

At Leeds Ian wore a white lab coat, which flapped as he walked briskly through the Department; the students were wary of his red hair and Findlay Johnson, the Departmental Curator, called him High Speed Gass. Bill Gaskarth had Ian for his moral tutor "whatever that might be" Ian said, "but come to me if you want any help; but I can tell you now, I won't lend you any money". Bill said you could argue with Ian, but you had better be sure of your facts. Other students were David Williams, Bill Fitches, Chris Neary, Stephen Self and a host of others. Later, many of these became Open University staff in one capacity or another.

Ian also began to supervise research students at Leeds. As we know, he had a talent for dealing with setbacks. Roy Bichan was to study the Great Dyke in Rhodesia and he had spent one season in the field when Ian Smith declared UDI, which stopped Roy's project in its tracks. Ian suggested a perfect alternative. A similar thing happened when the Turks invaded Cyprus in 1974 and Don Aldiss was left with a project in tatters. While Ian tried to sort out another one, he suggested that Don should book a holiday package to Spain and check if the Rhonda Massif is an ophiolite. Ian then arranged for Don to work in Oman, California and other places because by then, ophiolites had been discovered elsewhere.

Ian used to pick bright students and leave them alone, which I suppose is what a PhD is all about. Then when the time came, he taught most of them to write well; but this was often a traumatic experience for the students. "The first draft came back covered in red ink!" "Bullshit" was such a common remark; his students had a stamp made to save Ian getting writer's cramp. One student quoted a reference and Ian said "I don't think so, I went to his funeral ten years before that!" One could not pull the wool over his eyes because he knew everyone and his memory was amazing. Ian supervised 31 graduate students. At Leeds he had already begun projects in Saudi Arabia and he supervised several students from there.

In 1964, Ian led another Royal Society Expedition, this time to the Red Sea and Aden, mapping many volcanoes both on the

islands and on the mainland. They were a party of four: Ian, Don Mallick and Keith Cox, plus a research student of Charlie Drake's.

Ian had not entered the academic world quietly, and his time in academic life had hardly been conventional. When Kennedy came up to retirement and Robert Shackleton came over from Liverpool to help, Ian, with his friend Tom Clifford, was doing more and more administration within the Leeds Department of Geology. In an ideal world, Ian would have taken on the Chair at Leeds, but the university would not appoint an internal candidate.

Is this perhaps why Ian applied to the Open University?

The Open University — Professor of Earth Sciences

So here we have an ambitious, very competent geologist with management skills, who had reached Senior Lecturer level but would have to move in order to obtain a professorship. He applied for the new post of Professor of Geology at the Open University. (When Ian applied, the Chair was named Geology, but he changed it to Earth Sciences as soon he started.)

From the letter Ian attached to his application in January 1969, he wrote that he knew the OU would be a particular challenge, but he knew it could be good.

He argued for research: "Any scientist to keep abreast of his subject must have thought-provoking colleagues and be involved in his own research projects." He put the case for looking after his existing research group, now quite large.

Walter Perry, Vice-Chancellor, sat in on most of the interviews for the professorial posts. He remembered Ian's interview vividly because Ian was so good. Ian often said afterwards that he did not care whether he got the job or not (Fig. 13).

Walter Perry knew that if people with the stature of Ian Gass could be attracted, then the credibility of the project would be ensured. The Open University would be considered a proper university and not merely an exotic correspondence college.

Ian was reassured regarding his existing research students, who would be accommodated in other departments, especially Leeds and Bedford College, until such time as research facilities were available at the OU. Again, encouraged by Kennedy, Ian accepted the post. He chose Chris Wilson to be his lecturer. Chris had a passion for education in the earth sciences and his research interest in soft rocks, balanced Ian's main interest in Igneous Petrology. They had met in Sheffield when Chris organised the Inter-university Geological Congress on Uniformitarianism where Ian gave a talk.

In April 1969, the OU did not have a site.

Between April and October, Mike Pentz, Dean of Science prepared his academics for October 1969, the official start of the OU course preparation. At the time of the interviews, the academics believed they would be preparing lectures to be broadcast on the fourth TV channel, which was to be dedicated to education. The correspondence element would be the backup. Afterwards, this balance was reversed, which meant a much heavier writing load than they had bargained for.

Teaching at the OU

The S100 Science Foundation Course was produced by a Course Team in 15 months prior to January 1971. The Course Team, who initially met twice weekly, consisted of nine academics, BBC producers and Education Technologists, and latterly a General Editor. The Planning Committee of the university had recommended that S100 should be a course about science, but it did not take the Course Team long to agree that the best way to learn about science was to do science. So, in the absence of any knowledge about their consumers, all the course team could do was conceive the best and hope that it would be well received (Fig. 14).

The OU was the first opportunity to design a dedicated multimedia, teaching system and the education technologists Michael Neil and Tony Kaye called it a learning-teaching system where the lone student was central to their scheme. 'Objectives' were a novel approach provided to guide the student into disciplined and economical study. The scheduling of activities and deadlines were crucial; self-assessment was designed to reward the student, and success would be instrumental in keeping up the student's spirit. The 'Conceptual Diagram' was central to the planning of each week's work. Ian put all his themes on one diagram and high-lighted those that were relevant for that week. The conceptual diagram, however, did not survive the first year!

To summarise: Ian's success at the OU was phenomenal. He was Chairman of the Second Level Geology Course, the Earth's

Figure 13 Vice Chancellor of the Open University, Walter Perry (photo courtesy of The Open University).

Figure 14 Professor Mike Pentz, Dean of Science and Chairman of the S100 Course Team (photo courtesy of The Open University).

Physical Resources, Third Level Earth Sciences, Topics and Methods, Oceanography. Most of these were conceived by Ian's vision but he recruited exceptional members of staff to bring them to fruition. He was determined that his students, perhaps one thousand of them, should have a home experiment kit, including rock specimens, minerals and fossils, thin sections and a microscope to study them. Against overwhelming odds, he insisted on establishing a research department as well, which within a few years was ranked with Oxford, Cambridge and London (Gass 1989). Perhaps Ian's most monumental achievement was to raise backing and funding for the scientific study of the Oman Ophiolite (Lippard, Shelton and Gass 1986).

Conclusion

Ian Gass was indeed an ambitious man, but he channelled his ambitions, beguiled his personnel and used his academic power to progress his passion— the earth sciences. With this power came money, and money meant science. A lot of people are grateful to Ian for his generous attitude. Ian was delightful because he never expected people to be anything but themselves, to do what they said they would do, and to have a very good time doing it.

I offer this last figure as a 'caption competition' to readers. It is from the Seventh Biennial Report of the OU Department of Earth Sciences (Fig. 15; Potts *et al.* 1988).

Acknowledgements

This talk and paper is based upon material collected for a biography of Ian Gass.

The author would like to thank to all those people, family, colleagues and friends of Ian who agreed to be interviewed and who have provided correspondence, notes and photographs and encouragement. Thanks are due also to the Department of Earth Sciences at the Open University for access to Ian's academic papers. Numerous librarians have been most helpful. Also, I would like to thank a growing number of people who have read and made useful comments on the chapters: Hazel Prichard, Martin Corrick, Oneta Wilson and Duncan Woodcock.

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[Editor's note: TV programmes of the early versions of OU earth sciences courses are available to view in the OU Library at Walton Hall.]

Figure 15.

Geologists versus engineers — 19th-century conflicts over the supply of water to London

John Mather (Emeritus Professor of Geology, Department of Earth Sciences, Royal Holloway, University of London)

Introduction

In the 13th century London began to be supplied by springs from the suburbs, whose waters were fed to public cisterns and fountains, known as conduits, in various parts of the city (Fig. 1). By the 16th century these had become inadequate and in 1581 a Dutchman, Peter Morris (or Morrys), erected a waterwheel under one of the arches of London Bridge. The tidal stream in the Thames worked pumps, which distributed water through the streets in lead or wooden pipes. Supplemented by a canal, known as the New River, which brought spring water to the city from Ware in Hertfordshire (Fig. 2), the greater part of the growing metropolis was well supplied for the whole of the 17th century. Expansion to areas then beyond the range of existing mains resulted in the formation of additional water companies, which pumped water from the Thames and later from the River Lea. Over the next century, dissatisfaction with these water companies grew, firstly with the price of water and then with its quality. Water was pumped to consumers, directly from the river, despite the fact that it was dirty and contained a large amount of suspended matter.

Figure 1 View of the Conduit at Bayswater, published October 5th, 1796 by L. Stockdale, Piccadilly. The water that supplied the conduit came from the Westbourne, which arose by several small streams from the west side of Hampstead Heath. South of Bayswater, in Hyde Park, its valley is occupied by the Serpentine.

Improving water quality

In response to these concerns over quality, a Royal Commission was appointed to inquire into "the description, the quality, and the salubrity of the water" supplied to the metropolis. The commissioners concluded that the quality of water in the Thames was basically good but that as the river approached the city "it became loaded with a quantity of filth which rendered it disgusting to the senses and improper to be employed in the preparation of food." The commissioners attributed the extraneous matter in the Thames to sewage and refuse from factories in the neighbourhood of London and felt that most of it could be removed by filtration through sand (Anon 1828). The plan for filtration was adopted by many of the water companies but this failed to quieten public agitation and the engineer Thomas Telford was appointed to investigate alternative sources of good quality water that might be brought to London. He recommended that north London should be supplied by abstraction from the River Colne at Bushey near Watford in Hertfordshire (Telford 1834) (Fig. 3, *opposite*).

Figure 2 Chadwell Spring near Ware in Hertfordshire, one of the principal sources of the New River. A view published by J. Stratford, 112 Holborn Hill, London, September 8th, 1810.

The Stephenson report

The scheme was not implemented, but in 1840 a new project was brought forward to sink wells into the Chalk at Bushey and pump water into a large reservoir at the site from which it could then be fed into London. A test shaft, with boreholes at its base, was constructed and Robert Stephenson, the respected railway engineer, was asked to advise on the scheme. Stephenson reported later in 1840 and it was this report that initiated the dispute between geologists and engineers, which was to continue until well into the 20th century.

Stephenson noted the large surface area of Chalk that cropped out in the Chilterns, which was extremely porous and full of fissures. Rainfall was absorbed readily, which, in his view, largely prevented evaporation. He considered that there was a vast natural reservoir, which had an outlet under the coasts of Norfolk, Suffolk and Essex where the Chalk communicated with the ocean and, importantly, that there was no direct connection with the local rivers (Stephenson 1840).

There were a number of objections to his views principally from mill and property owners along the rivers. John Dickinson and Co. owned a number of paper mills along the River Gade (Fig. 3), and since 1835 had used a percolation gauge to measure the amount of rainfall that percolated through the soil to a lower level, and which was available for the supply of springs and

OUGS Journal 29 (2) Symposium Edition 2008, 48–51

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Figure 3 Map showing locations mentioned in the text (drawn by Jenny Bennett, 2008).

The London Spring Water Company

Regardless of the merits of the different arguments, the proposers of the Bushey scheme failed to generate the necessary investment to pursue the project and the scheme lapsed until 1850 when a new company, the London (Watford) Spring Water Company, again proposed to supply London with groundwater from the Chalk near Watford. The Company's engineer, Samuel Collett Homersham, put forward his views on what happened to rain that fell on the Chalk uplands in a report to the directors of the company (Homersham 1850). This assessment was to dominate the thinking of water company engineers for over 100 years.

Homersham considered that the rain behaved in one of three ways:

- a portion was consumed by evaporation or supported vegetation;
- another portion percolated through the surface and, held up by the impervious character of particular beds of chalk, fed local springs;
- and a far greater portion, encountering no such impervious beds, continued to descend until, arrested by the bed of clay at the base, filled the lower cavities and accumulated to such a height as to force its way through subterranean passages communicating with the sea. In this manner a large amount of water was discharged through the sand and shingle which covered the coast into the bed of the sea itself.

rivers (Fig. 4). The company's early measurements showed that only one third of the rainfall reached the Chalk, in contrast to Stephenson's view that this was almost 100% (Mather 2008). Another objector was the Reverend James Charles Clutterbuck, whose family owned property adjacent to the River Colne. Clutterbuck had measured water levels, at different periods of the year, in a series of wells in the ground between the Rivers Ver, Colne and Gade (Fig. 3). In his view, his measurements demonstrated that very little surplus water was available for abstraction from the Chalk at Bushey, when the water carried off by the Colne was subtracted from the water that percolated to the water table (Clutterbuck 1841).

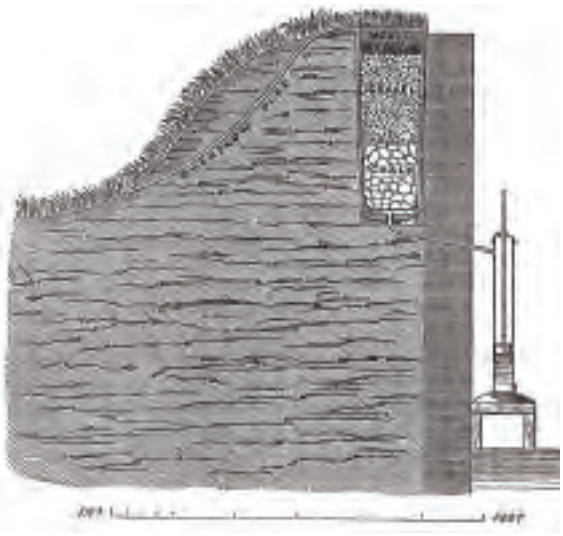

Figure 4 Sectional elevation of the percolation gauge used by J. Dickinson and Co. at Apsley Mill, Hemel Hempstead, Hertfordshire, as figured by Homersham (1855).

He proposed to sink a well, or wells, and to drive adits to intercept and tap the water in these lower cavities, arguing that all this water would otherwise run out to the sea through underground fissures and be wasted. According to him, the source from which this water was obtained could not diminish in yield or become polluted.

Homersham's report generated a rapid response from the mill owners and their allies the geologists. Clutterbuck read a paper at the Institution of Civil Engineers (Clutterbuck 1850) in which he reiterated his view that the natural outfall of the Chalk was not some distant coastline, but the mean tidal level in the River Thames below London Bridge. The position of the geologists was that the rivers, springs and Chalk groundwater formed one interdependent system, and that abstraction from one part limited the water available to the other components of the system. There was a complete connection between water at the top of the Chalk and water at the bottom by means of fissures, and the concept of two distinct types of water in the Chalk envisaged by Stephenson and Homersham was wrong.

The Cow Roast Lock pumping test

Support for the position taken by the geologists came from the results of a pumping test at Cow Roast Lock on the Grand Junction Canal, now the Grand Union Canal (Fig. 5, *overleaf*). In the early part of 1849 the canal company sunk a well into the Chalk adjacent to the lock and close to the source of the River Bulbourne, to supply the summit level of the canal.

Figure 5
Cow Roast Lock on the Grand Junction Canal (photograph © J. D. Mather, 2007).

When pumping started, water levels in local wells were lowered and John Dickinson and Co. protested that water was being abstracted that would otherwise flow into the river and downstream to their mills. The engineer, William Cubitt, was appointed by the Court of Chancery to investigate this claim, and three gauges were installed in the Bulbourne at various distances from the pumping well. As pumping commenced the gauges began to dry up as the water receded down the valley. The canal company argued that water feeding the River Bulbourne was from the top of the Chalk and that if the brick steining of the well was surrounded by puddled clay, and made watertight, communication with the upper Chalk water would be cut off and pumping would not affect the river. The puddling was duly carried out, but still the water receded down the valley, recovering to its original level once pumping ceased.

This evidence demonstrated that there were not two independent water-bearing units within the Chalk and that it was impossible to pump from the lower part of the Chalk without affecting the upper part (Mather 2008). On 2 April 1852 the Court granted a perpetual injunction to John Dickinson and Co. restraining the canal company from pumping from the well.

Geologists and engineers in conflict

The results of the Cow Roast test and the observational evidence on percolation and water level fluctuations accumulated by the geologists might have been expected to prove beyond reasonable doubt that there was a complete connection between the upper and lower parts of the Chalk. However, this evidence was not accepted by the water company engineers, who claimed that the sealing of the upper part of the Cow Roast well must have been defective, and that the percolation measurements carried out by John Dickinson and Co. were flawed. The water company engineers accused the mill owners and their geological allies of bias to protect their own interests, whereas they were acting solely in the public interest!

Discussions between the two sides generally took place at meetings held in the apartments of the *Institution of Civil Engineers*, where arguments were restated without any attempt at reconciliation. For example, the engineer John William Grover observed that: "In sinking [a well] in the Chalk near a river, the upper flint beds produce copious springs, when first tapped, of clear chalk-water, which is evidently the subterranean spring-water flowing to the river. As sinking is continued, the springs in the horizontal flint fissures have a very slow movement, the water comes up first like cream, gradually, after a few days' pumping, becoming clear and bright, but showing that the lower waters are travelling at a slow rate, and not in contact with the surface as the upper beds are." (Grover 1887).

In response, John Evans, a partner in John Dickinson and Co. and a former President of the Geological Society, commented that in his experience there was absolute evidence that there was a complete connection between water at the top of the Chalk and water at the bottom by means of fissures. In his view: "… it was much the same as filling a cistern with bits of stone, and saying, 'If you pump from the upper surface, you take water out of the cistern, but if you pump from the bottom of the cistern, you do not affect the level of the water in it.' He thought that on experiment it would be found that the water in the cistern would be lowered whether the pumping was from the top or from the bottom" (Evans 1887). A few years later, John Thornhill Harrison, an influential figure and one of the Engineering Inspectors of the Local Government Board, stated that "… it is seen that the Colne and Lea are taking their supply, only as it were, from the skin of the Chalk formation …" (Harrison 1891). A clearly frustrated

John Evans responded that if the engineers were right, "Are we to suppose that there is some hidden process for the manufacture of water going on within the bowels of the earth, so far as the Chalk districts are concerned." (Evans 1891).

The difference in approach and the scale over which observations were made by geologists and engineers involved in abstracting water from the Chalk can perhaps explain why disagreements persisted throughout the second half of the 19th century and well into the 20th century. The geologists were concerned with maintaining the flows of springs and rivers, and based their view of the amount of water available on careful measurements of percolation and variations in regional water levels, concluding that recharge was limited to a relatively small percentage of the mean annual rainfall. The rapid absorption of rainfall led the engineers to the view that vast amounts of water were available. When boreholes were drilled and water abstracted, they observed how yields suddenly increased as the drilling rods broke through flint bands or intersected fissures, leading to the conclusion that there were distinct sheets of water. As John Grover commented to John Evans, who incidentally was his cousin, "Any one who had sunk a Chalk well and had stood over the boring-rods would comprehend the Dr Evan's idea was a mistaken one." (Grover 1887).

A solution

The relationship between rainfall, Chalk groundwater and river flows was not to be settled until the 1970s. Proposals to augment river flows with groundwater in the River Thames catchment led to a major pilot scheme to investigate the effect on river flows of pumping from wells adjacent to and more remote from tributary rivers. The view that was still prevalent among many water engineers was that deep groundwater could be exploited without affecting spring discharges, which were deemed to have a shallow origin. This view was not shared by the Chief Geologist of the Water Resources Board, Jack Ineson, and his staff, who insisted on the pilot scheme to demonstrate unequivocally the effect of abstracting groundwater on river flows (Downing 2004). One might argue that this had already been demonstrated in the 19th century and that knowledge of the historical debate that took place at that time might have saved considerable time and money.

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‘God’s great plough’ — Louis Agassiz and the Ice Age

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Abstract

Louis Agassiz (1807–1873), while not the first to consider features such as erratic blocks, moraines, striated bedrock and *roches moutonnées* to have been produced by glaciers, was instrumental in introducing the concept of a large-scale glaciation. Utilising the term ‘Ice Age’ as supplied by his friend Schimper, and building on the impressive body of field evidence collected by forerunners Venetz and de Charpentier, he presented an outline of his ideas in 1837, and developed them in more detail in 1840. Further work conducted with a research team stationed on the Unteraar Glacier for several field seasons yielded much further data on the structure and activities of glaciers. Following a move to America in 1846, he recognized evidence of glaciation, particularly in the eastern USA. An expedition to Brazil had, as one of its aims, the search for evidence of glacial features in more southerly latitudes; Agassiz believed that glaciation encroached toward the equator, affected the greater part of the northern hemisphere and accounted for the total extinction of animal life in the most recent of Cuvieran ‘revolutions’. His glacial work brought controversy with others, particularly Schimper, de Charpentier and Forbes, over claims of priority.

Louis Agassiz: biographical background

1807 saw the fourth coalition of nations — namely Prussia, Russia, Saxony, Sweden, and the United Kingdom — pit themselves against the forces of Napolean Bonaparte’s French Empire. As Napolean’s troops routed Russian forces in the east, the infinitely more peaceful collection of villages called Motier (Canton Fribourg, western Switzerland), celebrated the birth of Louis Agassiz (1807–1873) (Fig. 1). Pastor Rodolphe Agassiz and his wife, Rose, had, by then, four other children, but none had survived infancy, although Louis (baptized Jean Louis Rodolphe) was later succeeded by younger brother Auguste and two sisters (Olympe and Cécile).

Naturally inquisitive and studious, Louis was schooled by his father during his early years, then passed quickly through a meritorious education at Bienne, Lausanne (in the adjacent canton of Vaud), Zürich, Heidelberg and Münich. This path brought him under the tutelage of the most eminent European naturalists of the day, including the palaeontologist Heinrich Georg Bronn (1800–1862), botanist Theodor Bischoff (1807–1882), zoologist Friedrich Sigismund Leuckart (1794–1843) and embryologist Friedrich Tiedemann (1781–1861). Tiedemann was also instrumental in introducing Agassiz to two other outstanding students: Alexander Braun (1805–1877) and his friend Karl Schimper (1803–1867), both of whom were particularly interested in botany. The three spent much time in each other’s company and a healthy rivalry seasoned the friendship; Agassiz often visited Braun at home, getting to know one of Braun’s sisters, Cécile, particularly well – an acquaintance that would eventually lead to romance and marriage.

Figure 1 Portrait of Louis Agassiz (from Agassiz 1833–1843, Recherches sur les Poissons Fossiles*; reproduced by kind permission of David Ward).*

Figure 2 Portrait of Georges Cuvier (1769–1832).

Louis rapidly established a reputation in ichthyology, which took him to Paris to study with the great Baron Georges Cuvier (Fig. 2). Agassiz’s *magnum opus* on fossil fishes (5 volumes) described *c.* 1,500 new genera and species (Agassiz 1833–43; Gaudant 1980; Duffin 2007).

Gifted with languages and possessed of enormous drive, enthusiasm and an indefatigable spirit, very early in his career he was acclaimed both as a charismatic, winsome teacher and as an innovative thinker. The vast scope of Louis’s research plans usually exceeded his ability to complete them, and he was never far from controversy; his father once wrote that he had “a mania for rushing full gallop into the future” and he managed to live constantly on the cusp of financial ruin (letter dated 21 February1828; Agassiz 1885, 65). Later emigration to the United States revitalized his research, brought nationwide popularity as a lecturer and saw him spearheading American anti-Darwinism as well as setting up the Museum of Comparative Zoology at Harvard (Lurie 1988; Duffin 2007).

Setting the scene

1 Cuvier and the mammoth

Although baptized Jean-Léopold-Nicholas-Frédéric, the great anatomist, Baron Cuvier (1769–1832) adopted and used the name Georges after an elder brother who died in early childhood (Rudwick 1997, 1). Born into a modest bourgeois family at Montbéliard, in the then French-speaking Duchy of Württemberg, Cuvier studied at Stuttgart before gaining employment as a tutor in Caen, where he was relatively untouched by the effects of the ‘Terror’. He eventually moved to Paris in 1795. Here, working initially as understudy to the resident elderly professor of animal anatomy, his rise was meteoric (Rudwick 1997; Tacquet 2006).

Cuvier read his ‘Treatise on the species of elephants, both living and fossil’ (Cuvier 1796, 1799) to the gathered luminaries of the Science section of the Institut de France on 1st Pluviose, year IV of the newly designated French revolutionary calendar (21 January 1796). His claim was that the study of elephants would “shed light for us on the obscure and intriguing history of the revolutions of the globe” (Cohen 2002, 105). From close observation of the osteology of extant elephants, Cuvier was able to assert for the first time that the African and Indian elephants

OUGS Journal 29 (2) Symposium Edition 2008, 52–65
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belonged to two distinct species, marshalling details of skull, tusk and dental morphology in defense of his thesis. He then introduced mammoth bones into his treatise under the subheading 'On lost elephant species'. Largely unaltered mammoth bones and tusks had long been known from Siberia; local folklore explained their presence as giant underground mole-like creatures that, on breaking through the surface, instantly perished. There had been earlier suggestions that these bones belonged to elephants, but Cuvier was now able to prove that they belonged to a distinct, 'lost' species, different again from the celebrated 'Ohio animal' (the Mastodon) that had been sent back to France and the Cabinet du Roi by Baron Charles de Longueuil in 1740 (Daubenton 1764; Cohen 2002; Semonin 2000).

Cuvier remarked that these fossil "animals thus differ from the elephant as much as, or more than, the dog differs from the jackal and the hyaena. Since the dog tolerates the cold of the north, while the other two only live in the south, it could be the same with these animals" (Cuvier 1796, translated in Rudwick 1997, 22). Here, Cuvier was offering a subtle critique of Buffon's (1778) proposal that the earth had cooled gradually from an incandescent body until the current surface temperatures were reached. Indeed, Buffon undertook a series of carefully planned experiments involving the heating of iron shot and recording the time it took for them to cool to normal temperatures (Wyse Jackson 2006, 105ff.); by scaling up his results for a body the size of the earth, a multitude of assumptions notwithstanding, he was able to propose, with adjustments duly made for the effects of solar heating, the diversity of materials encountered at the surface etc., an age of 74,832 years (Roger 1997, 410). Obviously, the attitude of the earth would have meant a greater rate of cooling at the poles. Once global temperatures were sufficient to sustain life, the ubiquity of animal distribution would be affected by differential cooling, such that animals preferring warmer temperatures would have to migrate towards equatorial refugia. By describing fossil elephant remains from northern climes, Cuvier was able to state:

> "while relieving us of the necessity of admitting a gradual cooling of the earth, and while dispelling the gloomy ideas that presented the imagination with northern ice and frost encroaching on countries that today are so pleasant, into what new difficulties do these discoveries not now throw us?" (Cuvier 1796, translated in Rudwick 1997, 22)

For the moment, Cuvier left the argument there, but he returned to the discussion in a later review (Cuvier 1806). In a careful analysis of what we would now call taphonomy, Cuvier concluded that mammoths lived as animals in the latitudes where their remains are currently found, rather than having been transported there by some geological agency. The discovery of specimens of mammoth and rhinoceros with traces of skin and soft parts preserved in ice meant that they must have "disappeared from there only by a revolution", an event which "must have been sudden" (Cuvier 1806, translated in Rudwick 1997, 93). Agassiz would later invoke the demise of the mammoth in his discussion of the implications of large-scale glaciation; he would provide the mechanism for Cuvier's 'revolution' that would, unfortunately, revive the 'gloomy ideas' of ice and frost encroaching into more comfortable climes.

2 Glaciers: movement and products

In his *Autobiography*, Charles Darwin recalled an old man talking about an erratic boulder in the town of Shrewsbury in Shropshire (the 'Bellstone', currently located in the courtyard of the Morris Hall in Shrewsbury), saying that "the world would come to an end before any one would be able to explain how this stone came where it now lay" (Darwin 1887, 6). Attempts were being made to account for the origins of these 'foundlings' as the Germans called them, even then.

Bristolian, Sir Nathaniel William Wraxall (1751–1831) was employed by the East India Company from 1769. While journeying around southern Finland on leaving the service, he was amazed at the tortuous path taken by the road on which he was travelling; the somewhat serpentine route was determined by large numbers of scattered boulders. He remarked that, "it seems as if they had fallen from the sky" (Wraxall 1807, 215). Indeed, Jean-André de Luc (1727–1817), Reader to Charlotte, queen consort of George III, effectively suggested just that as a potential mechanism to account for their origin. He proposed that topographical variation in the earth's surface reflected differential subsidence of the crust into large underground voids. Compression of the 'elastic fluids' occupying these subterranean caverns by such collapse supposedly caused them to be projected violently through cracks and fissures, taking large masses of rock with them (North 1943, 7). Similarly, the Huguenot Swiss polymath and disciple of Leibniz, Louis Bourguet (1678–1742), came to the conclusion that granitic erratics in the Jura had not rolled downslope as there were no immediately adjacent mountains to act as a source. Instead, he commented that the blocks were so large and so numerous as to give the impression that they had tumbled from the clouds (Bourguet 1729, 198).

Emanuel Swedenborg (1688–1772), the Swedish scientist and, in later life, theologian and founder of the Church of New Jerusalem, noted that erratic boulders were to be found on the Swedish plains, in lakes and also in the mountains. He suggested that the wave-tossed deep salt waters of a universal ocean exhumed sand, clay and boulders from the sea floor, smoothing them and transporting them to their final resting places (North 1943, 5). This is not too distantly removed from the idea of the universal deluge associated with the Noachian Flood.

Jean-Étienne Guettard (1715–1786), the pioneering French geologist, proposed in 1762 that the boulders strewn over the plains between the Baltic and the Carpathians were due to wholesale weathering and *in situ* decomposition of pre-existing granite mountains, of which they constituted the only remaining evidence (North 1943, 7).

The Iceberg, or Drift theory of boulder transport originated in 1742 with Daniel Tilas (1712–1772), a Swedish mining engineer (North 1943, 13). Taken up by numerous later authors, including Goethe (1749–1832), the idea was embellished by the Berlin mathematician and natural philosopher, Wrede who suggested that erratics littering the North European Plain had been transported from the north on drifting ice floes. Charles Lyell (1797–1875) further championed the idea in Volume 1 and subsequent early editions of his *Principles of Geology* (Lyell 1830), and Darwin found that letters on the subject from Lyell rejoiced "the innermost cockles of my heart" (letter to J. D. Hooker, 26 April 1858).

The Swiss aristocrat, Horace-Bénédict de Saussure (1740–1799) was fascinated by the Alps. He tramped across them regularly, studying their botany geology, topography, meteorology

and, of course, their glaciers. It seemed as if, everywhere he went, he fell under the shadow and spell of Mont Blanc – "It had become with me a species of disease", he once wrote (de Saussure 1786, IV, 219). His obsession was so great that he offered a reward in the late summer of 1760 to the first persons to scale the mountain, a bounty that was not claimed until 8 August 1786. De Saussure himself was, in 1787, part of the third successful expedition to the summit, and the first scientist to make the ascent.

Making many observations of glaciers during his alpine travels, de Saussure appreciated that the moraines forming the hummocky ground at the glacier snout could be traced farther down the alpine valleys, suggesting that the ice had extended farther in the past. He found a similar distribution of erratic boulders, but it was James Hutton (1726–1797), the Scottish geologist and proposer of the Principle of Uniformitarianism, who later suggested in his *Theory of the Earth* (1795), on the strength of de Saussure's descriptions, that glacier ice was the only possible means by which the boulders had been transported to their current positions. Huttons' successor, the Edinburgh Mathematician and Natural Philosopher John Playfair (1748–1819), visited the Alps and arrived at the same conclusions, commenting that "for the moving of large masses of rock, the most powerful engines without doubt which nature employs are the glaciers" (Playfair 1822, 384).

Agassiz and ice

1 Beginnings

An early encounter with ice when he was about seven years old nearly cost Louis both his own life and that of his younger brother (Agassiz 1885, 6). A fair was being held on the opposite shore of Lake Morat, some two miles distant, and his father was there. Louis decided to skate his way across the frozen lake with Auguste so that they could return that afternoon with his father. Rose's suspicions were aroused when she saw other young skaters returning from the lakeside for their dinners. After being told the situation, she rushed to an upstairs window and trained a telescope onto the lake, only to spy potential disaster: Louis was stretched across a large open fissure in the ice and was acting as a bridge for his younger brother to cross the watery divide (Holder 1893, facing page 1) (Fig. 3). Slightly frantic, she pressed a workman to skate across the lake to get them; he caught up with them on the opposite shore and returned them safely — across the same divide that had previously hampered their journey!

Figure 3 'Agassiz [approximately 7 years old] helping his little brother across a crack in the ice' (from Holder 1893, facing page 1).

Figure 4 Glacial erratic: the Pierre-á-Bot, near Neuchâtel, Switzerland (from Forbes 1845, 39).

The Jura, Agassiz's playground as a young boy, is replete with glacial phenomena, despite there being no glaciers in the immediate vicinity. The Pierre-á-Bot (Fig. 4) is a renowned erratic near Neuchâtel that attracted visitors in the early 19th century as it still does today; in his younger years, Agassiz had no inkling that he would later be seeking an explanation for its presence.

Having been encouraged by his mother to seek gainful employment on the death of Cuvier and the consequent loss of his security in Paris, Agassiz demonstrated considerable political acumen in the process of applying for a professorship in natural history at Neuchâtel; he duly arrived in November 1832. Things moved quickly as he established classes, enthused the locals about science, built up the museum of natural history, virtually took over the local printing works with his publishing enterprises, and married Cécile, Alexander Braun's sister. His main interest at this time was fossil fishes, but he also wrote extensively on other geological and zoological subjects. Open-hearted and generous, Agassiz opened his home to a succession of students, artists, lithographers and helpers who came to study with the young Swiss, much to his new wife's consternation. Indeed, Cécile found two characters in the Agassiz entourage particularly odious: she was offended by the outspoken atheistic views of Carl Vogt (1817–1895), and was openly suspicious of Édouard Desor (1811–1882), who seemed to have an uncanny ability to extract money from Louis. With their home and finances at full stretch, Cécile became increasingly uncomfortable.

By 1836, work on his *Recherches sur les Poissons Fossiles* was progressing well: individual parts ('livraisons') were rolling off the presses and dispatched to those who had subscribed in advance. Although exciting, this was not a stress-free time for Agassiz. Constantly concerned about finances, he confessed in a letter (October 1835) to Alexander von Humboldt (1769–1859) that the "enterprise [is] so vast in proportion to my means" that "having begun it … my only safety is in success … though often in the evening I hardly know how the mill is to be turned tomorrow." (Agassiz 1885, 257). Indeed, it is almost as if Agassiz was the personification of Samuel Butler's (1835–1902) aphorism, "All progress is based upon a universal, innate desire on the part of every organism to live beyond its income". This rather piecemeal form of publishing meant that von Buch, while rejoicing in their content, found the system "altogether diabolical" (Humboldt to Agassiz, May 1835, *in* Agassiz 1885, 256), and Humboldt himself felt forced to explain that others "constantly complain of this

fragmentary style of publication, which is the despair of those who have not the leisure to place your scattered sheets where they belong and disentangle the skein" (Humboldt to Agassiz 2 December 1837, *in* Agassiz 1885, 266). A new distraction was just around the corner, however — one that would captivate his imagination but do nothing to ameliorate his ailing finances.

Jean de Charpentier, co-student earlier in the century with Humboldt and von Buch at the Freiburg School of Mines, had taught Agassiz at Lausanne and the two had kept in touch. At about the time of Louis's marriage in 1833, de Charpentier invited Agassiz to visit him at Bex (in the Rhône Valley, Canton Vaud) where he was now Director of the Salt Works. An extremely hospitable character, de Charpentier had a reputation for opening his home to a wide, international range of natural historians. Agassiz was only able to accept the invitation for the summer of 1836; he was in need of a holiday. Now a family man (his son, Alexander, later a geologist of considerable repute in his own right, was born the previous winter), Agassiz rented lodgings in Bex and visited de Charpentier daily (Marcou 1896, I, 84). Together with a succession of other visitors (including Karl Schimper), de Charpentier and Agassiz visited a number of localities around Bex and the neighbouring Valais, including the glaciated areas of Chamonix and Les Diablerets. These latter peaks were so-called because legend recounted that demons haunted the mountains; the locals insisted that proof of this fact lay in the noises that issued from the region, claiming that for sport, the demons supposedly played ninepins with rocks, some of which landed on glacier surfaces. During their excursions, de Charpentier showed Agassiz the moraines of the Rhône Valley, the erratics littering the area and scratched bedrock surfaces, accounting for their origins by former extensions of the valley glaciers. Sceptical at first, since he followed the iceberg hypothesis of Lyell, Agassiz was finally convinced. He quickly assimilated the facts and arguments and was able to integrate them into an overarching picture. With the evangelical fervour of a new convert, he returned to Neuchâtel and observed, with new eyes, evidence of glacial activity at a considerable distance from the nearest glacier. Throughout the following winter, as his second wife later observed, "a new chapter of nature was all the while unfolding itself in his fertile brain" (Agassiz 1885, 263).

2 The discourse of Neuchâtel

On 15 February 1837, the Société Neuchâteloise des Sciences Naturelles, a body inaugurated by Agassiz on his arrival at Neuchâtel (Lurie 1988, 74), had its meeting. The date coincided with the 34th birthday of Louis's friend, Karl Schimper (Fig. 5). Schimper noted that his own birthday coincided with that of Galileo Galilei (1564–1652), and requested that his friends call him Galileo as a consequence. Particularly remembered for his contributions to botany, Schimper had visited de Charpentier together with Agassiz the previous summer. When Louis returned to Neuchâtel and investigated the glacial features of the Jura, however, Schimper was still at Bex, eventually joining Agassiz at home as his guest later in the year. The two friends presumably spent evenings discussing a wide range of natural history topics, including the emerging glacial theory. Agassiz had given a public lecture on the subject during the winter (Carozzi 1966, 64), but the February meeting belonged to Schimper. Having delivered two botanical papers, he then distributed a small item of poetry. The title was 'Über die Eiszeit' ('On the Ice Age'); this

Figure 5 Portrait of Karl Schimper (1803–1867) by C. Geyer (1866).

short poem, 80 lines long, part humorous and part scientific, introduced, for the first time, the term that would become so entrenched in geological thinking and popular culture.

The Société Helvétique des Sciences Naturelles had been meeting together and publishing their proceedings (*Actes*) since 1815. Agassiz, although only 30 years old, was the President of the Society in 1837, the year after his epiphany at Bex, and the 22nd annual meeting took place at Neuchâtel. With his work on fossil fishes moving inexorably onwards, the gathered scientific dignitaries would, no doubt, have expected Agassiz's opening address to be concerned with that subject. Instead, however, he gave a hastily constructed paper on glacial theory, which he reputedly wrote throughout the previous night (Carozzi 1966, 64). Famous though it has become, this paper is very scarce indeed, never having been printed separately at the time, and the proceedings containing it having a very small print run. Marcou (1896, 89ff.) reproduces the original French text, while Carozzi (1967, xli ff.) gives a very useful English translation.

Paying homage to his Swiss predecessors, Venetz and de Charpentier, Agassiz gave a clear exposition in his 'Discours' of the evidence, with additional observations, for the former extension of glacial ice, which had already been shown to him by Venetz and de Charpentier at Bex: moraines, erratic blocks and striated rocks. His argument was essentially:

1 that the ridges of morainic material associated with the flanks and toes of existing glaciers, forming ridge-like, hummocky ground concentrically arranged at glacier margins, are also known in areas where now no glacier exists (e.g. on the shores of Lake Geneva);
2 that erratic boulders strewn over these moraines and on the surfaces of the glaciers themselves are also known at locations of high elevation, where glaciers no longer exist; and
3 that rocks too hard to be easily weathered show polish and are grooved in the direction of the long axis of the valley down which glaciers must have travelled to produce the moraines and erratics, e.g. the flanks of the Rhône Valley, which show such polishing all the way to the shores of Lake Geneva.

Having established the means of identifying the former existence of glacial ice where no contemporary ice existed, Agassiz paused to ask the question, "Did the most extended glaciers come down from the top of the Alps, or was there a time when ice formed naturally beyond the limits just assigned to it, extending perhaps once as far as the Jura, and even beyond?" (Agassiz 1837, xv–xvi; Carozzi 1967, il). Using evidence from the distribution of erratics in the Alps and the Jura, he then systematically dismantled the best explanations so far: de Charpentier's suggestion that alpine valley glaciers had transported them thence; and the favourite alternative, transportation by flood waters. Instead, Agassiz envisaged:

> "the greatest catastrophe which has ever modified the relief of the earth, occurred when the surface of the latter was covered with ice, at least from the North Pole to the shores of the Mediterranean and the Caspian Sea." (Agassiz 1837, xxv; Carozzi 1967, liv).

One can just imagine the sharp intakes of breath from the collected audience: an ice sheet covering an entire hemisphere? Having so carefully built his thesis, Agassiz now indulged in some fairly wild speculations as to cause, in spite of the fact that he states "I do not feel that I am going beyond the consequences that the facts permit" (Agassiz 1837, xxiii; Carozzi 1967, liii). Implicitly accepting the cooling earth hypothesis of Buffon and invoking the revolutions or 'dèbâcles' of Cuvier, Agassiz speculated that variations in global temperature from this downward trend could be accounted for by the history of life. At times of extinction, the loss of animal life meant that the loss of their collective radiant heat caused the planet to cool, thus stimulating a plunge in global temperature that "must have been responsible for the formation of the huge masses of ice which covered the earth all over the places where erratic boulders are associated with polished rocks like ours" (Agassiz 1837, xxiv; Carozzi 1967, liv). The falling temperatures must have been responsible for the preservation of the Siberian mammoths described by Cuvier. With the creation of new life forms, global temperatures recovered, glacial ice caps disappeared and conditions ameliorated.

In the closing paragraphs of the 'Discours', Agassiz remarked (1837, xxxi; Carozzi, lviii): "I am afraid that this approach will not be accepted by a great number of our geologists". That statement was demonstrably true, and its validity confirmed by the immediate response of the audience: bedlam reigned in the ensuing discussion. Poor Amanz Gressly (1814–1865) was due to read his paper next, in which he was to develop the facies concept, a fundamental contribution to stratigraphy; overwhelmed by the heated discussions, however, he just rolled up his notes and stuffed them in his pocket — he would submit the paper for publication without the formality of a public reading (Cross and Homewood 1997)!

De Charpentier was embarrassed to be associated with such ramblings. Léopold von Buch was, predictably, horrified. He is reported to have raised his hands and, appealing to that great alpine explorer and geologist, Horace Bénédict de Saussure (1740–1799), with his head bowed toward the distant Bernese alps, uttered the cry "O Sancte de Saussure, ora pro nobis!" ("Oh Saint de Saussure, pray for us!"). Frédéric Eugène Terrisse (1806–1840), a public official, recorded in his diary that von Buch fought 'rather ruthlessly' against the young Swiss (Terrisse 1931; Rivier 1931; Carozzi 1967, 67), and Agassiz was later to reflect somewhat euphemistically that, "It was not an easy task to be an opponent of Léopold von Buch in 1837" (Carozzi 1966, 65).

The next day, 25 July 1837, was the day of the field excursion. Elie de Beaumont (1798–1874) joined the meeting and, leaving at 4:15 a.m. for the Jura mountains, found himself in the leading carriage with von Buch and Agassiz — one wonders what the atmosphere was like in there. Once in the field, de Beaumont was 'as cold as ice', von Buch, by now 63 years old, spent the time walking briskly, eyes locked on the ground in front of him with his characteristic gait (bent-kneed, placing his feet, shod with loose-buckled pumps, with trembling exactitude) mumbling and complaining to himself, while Agassiz walked in splendid isolation, a quarter of a league in front of the party.

Neither was the literary fallout from the meeting much less biting. Humboldt wrote to Agassiz on 2 December 1837 with the following recommendation:

> "I think that you should concentrate your moral and also your pecuniary strength upon this beautiful work on fossil fishes. In so doing you will render a greater service to positive geology, than by these general considerations (a little icy withal) on the revolutions of the primitive world; considerations which, as you well know, convince only those who give them birth … Your ice frightens me … No more ice, not much of echinoderms, plenty of fish, recall of ambassadors *in partibus*, and great severity toward the booksellers, an infernal race, two or three of whom have been killed under me." (Agassiz 1885, 267)

Amicable relations were swiftly restored with von Buch, although in a letter dated 22 December 1837 he wrote to Agassiz saying that, although he liked his "way of looking at nature … how much I prefer you in a field which is wholly your own [i.e. fossil fishes] than in one where you break in upon the measured and cautious tread, introduced by Saussure in geology" (Agassiz 1885, 273–4).

It cannot be said that Agassiz did not respond to this advice, although Humboldt and von Buch would have been surprised at the way in which he did. Rather than concentrating on fishes alone, his expanding interests necessitated the employment of a secretary, so Louis hired German political refugee Édouard Desor (Fig. 6; Kaeser 2004). The 'measured and cautious tread' of de Saussure would become footprints within which he would place his own; Agassiz determined to study glaciers in a way that can only be described as close-up and personal; he spent the next eight summers (bar one) on the glacial ice of Switzerland, with the intention of accumulating a systematic body of knowledge to support his contentions of the existence of an ice age. Before his field studies were up he intended to understand not only the morphologies of glaciers but also how they worked.

Figure 6 (above) Portrait of Édouard Desor from a carte-de-visite, circa 1853, (below) Desoria glacialis *(now* D. saltans*), a 2–3mm long cold-temperature collembolan ('glacier flea'), named in honour of Édouard Desor (from Desor 1844, facing page 144).*

3 *Études sur les Glaciers*

In the following year (1838), after visiting the glaciers of the Chamonix area, Agassiz attended the Geological Society of France meeting at Porrentruy. Here, he championed his views on glaciation with eager enthusiasm.

During the summer of 1838, Agassiz studied the Aletsch, Rhône and Unteraar glaciers. The latter (latitude 46º35´N, longitude 8º15´E, a valley glacier currently13.5km long and covering 24.1km^2; Steiner *et al.* 2008) consists of the confluence of two ice stream

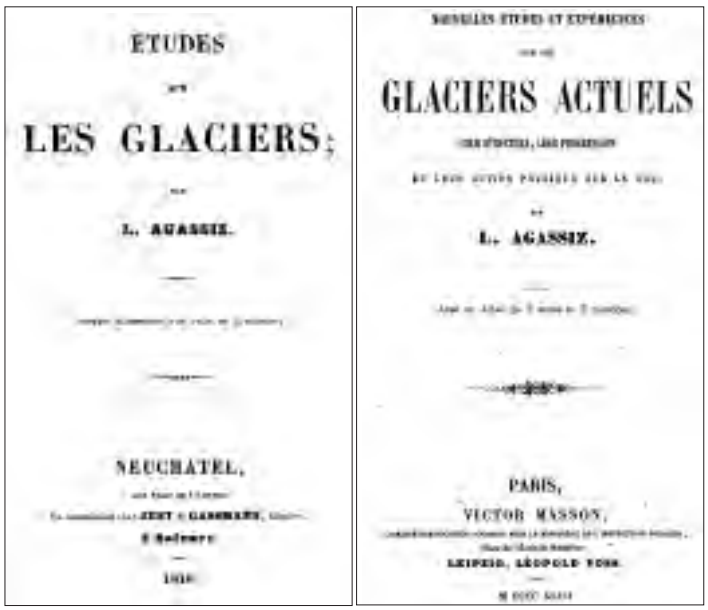
distributaries, the Lauteraar and the Finsteraar Glaciers, which flow together at a resistant rock feature known as the Abschwung. Agassiz came across the cabin of Franz Joseph Hugi (1791–1855; a monk and alpine explorer from Soleure), which had been built in 1827 (on the evidence of dated papers surviving within it) just below the Abschwung; now, however, it was some 4,000ft (1,219m) farther down the glacier. Agassiz was so enthused with his glacial studies that summer that he wrote to William Buckland (1784–1856; Duffin 2006; Fig. 7) in Oxford saying, "Since I saw the glaciers I am quite of a snowy humour, and will have the whole surface of the earth covered with ice, and the whole prior creation dead by cold. In fact, I am quite satisfied that ice must be taken [included] in every complete explanation of the last changes which occurred at the surface of Europe" (Agassiz 1885, 289).

Figure 7 Bust of William Buckland (1784–1856) in Oxford University Museum.

The winter of 1839 saw Agassiz hard at work writing his celebrated *Études sur les Glaciers* (Agassiz 1840; Carozzi 1967; Fig. 8). This, the first book to dedicate itself wholly to glaciers, was published simultaneously in French and German (as translated by Carl Vogt). Agassiz corrected the proofs while living on the ice of the Aar Glacier in the summer, and the volume with its folio atlas of 32 beautiful plates (e.g. Fig. 9) appeared in September 1840.

While giving due recognition to de Charpentier and Venetz, Agassiz gives a history of former research and then goes on to pay attention to glacier structure, noting that surface snow gives way via granular snow to glacial ice. This, he says, is unlike the ice forming on lakes, ponds and rivers, because instead of being slippery and polished, it has an uneven surface, making it very easy to walk over. This uneven-ness is due to "a multitude of angular fragments of ice … separated by innumerable capillary cracks" (Agassiz 1840, 31; Carozzi 1967, 17). He notes that the larger fragments are up to 80mm across, but rather than being crystalline, vary considerably in shape. He goes on to recommend a novel method of viewing the individual crystals:

> "a slight moistening of the surface with acid or any coloured liquid will outline them immediately with the highest degree of sharpness and at the same time a light crackling noise may be heard. Warm urine is the most readily available reagent that could be used for this purpose. Those who perform this small experiment will be struck by the effects produced on glacier ice in comparison with those on snow or ordinary ice" (Agassiz 1840, 34; Carozzi 1967, 18).


ETUDES

SUR

LES GLACIERS;

PAR

L. AGASSIZ.

NEUCHATEL,

1840.

NOUVELLES ETUDES ET EXPÉRIENCES

SUR LES

GLACIERS ACTUELS

PAR

L. AGASSIZ.

PARIS,

VICTOR MASSON,

LEIPZIG, LÉOPOLD VOSS.

1847.

Figure 8 Title pages of Agassiz's Études sur les Glaciers *(1840) and* Nouvelles Études et Expériences sur les Glaciers Actuels *(1847).*

Figure 9 'Glacier de Viesch' from Agassiz (1840, tab. 10).

Agassiz was unwilling to discard the biological explanations for the origins of the Ice Age, first outlined in the 'Discours', eliciting the comment from Adam Sedgwick that, "I have read his Ice-book. It is excellent, but in the last chapter he loses his balance, and runs away with the bit in his mouth (Sedgwick to Murchison, 26 November 1840, in Clark and Hughes 1890, II, 18). Venetz, de Charpentier and Hugi were all unhappy with the explanations. Agassiz's volume was received well in the United States, however, especially by the highly respected Edward Hitchcock (Carozzi 1966, 73).

4 Visit to England

Among British geologists, Agassiz formed particularly close relationships with William Buckland (1784–1856), Reader in Mineralogy at Oxford and later Dean of Westminster (Duffin 2006), and his two students turned Members of Parliament, Lord Enniskillen (William Willoughby Cole; 1807–1886) and Sir Philip de Malpas Grey Egerton (1806–1881) (Duffin 2007). Buckland was instrumental in inviting Agassiz to Britain in order to examine fossil fishes in 1834, and a further visit was made in 1835. Buckland himself had an intense interest in the dating and

origins of 'diluvial' gravels (Rupke 1983), and took the opportunity to visit Agassiz in Switzerland. Agassiz was, by now, consumed with ideas of glaciation on a large scale. As he showed Buckland the evidence of former ice activity in the Bernese Oberland, the Oxford Professor became convinced.

Knowing that Agassiz was committed to searching for evidence of glacial activity beyond the Alpine region (Davies 1968, 132), Buckland invited Agassiz to Britain once again in 1840. Agassiz could catch up with old friends, make new contacts, study new finds of fossil fishes, present papers at learned societies and attend the British Association for the Advancement of Science Meeting at Glasgow. That is exactly what Agassiz did. Furthermore, on Tuesday 22 September Louis read a paper about the ability of glaciers to polish and scratch rocks and announced his intention to look for such evidence of former glaciation in the Highlands of Scotland, and that he was confident of finding it around Ben Nevis. Between sessions at Glasgow, Louis took the opportunity to investigate the city, finding evidence of glaciation everywhere he went (Davies 1968, 133).

Once the meeting had adjourned, on 23 September, Agassiz and Buckland made their way northwards to the Scottish Highlands. Travelling via Loch Lomond and adjacent lochs and taking in some of the glacial features that Buckland had tentatively identified on an earlier visit, they reached Inverary where they famously crossed an enormous terminal moraine in order to pay a visit to the Duke of Argyll. From here they passed via Loch Awe and the Brander Pass to Loch Etive, encountering moraines, erratics and polished rock surfaces as they went. It was in the Fort William area that Agassiz had boldly prophesied that traces of the action of former glaciers would be found, and they were not disappointed; an excited Buckland wrote to Aberdonian Natural History Professor, John Fleming (1785–1857), saying, "We have found abundant traces of glaciers around Ben Nevis" (Gordon 1894, 141).

Some of his finest roches moutonnées were found at the entrance to the Loch Treig valley, and then the pair arrived at Glen Roy (Fig. 10). Here, the Parallel Roads, first described by Thomas Pennant (1725–1798) presented their own challenge. A wide variety of explanations had been advanced to explain the presence of these prominent benches, which marked the walls of the Glen. The most recent was that of Charles Darwin, made the previous year (Darwin 1839), who suggested that they represented the marine strand lines of raised beaches. Agassiz immediately identified them as the former strand lines of an ice-dammed lake, and submitted his explanation to *The Scotsman* (7 October 1840).

Figure 10 The Parallel Roads of Glen Roy, Scotland (© M. J. Hambrey, reproduced with kind permission).

From the Highlands, Agassiz travelled to Scotland to visit Lord Enniskillen at Florence Court, and was not surprised to find polished limestones and moraines in the immediate vicinity. A return to Edinburgh in October resulted in more evidences of glaciation. Finally, both he and Buckland presented papers concerning the former existence of glaciers in England, Scotland and Ireland at the 4 November meeting of the Geological Society of London. The British geological establishment was not generally convinced, however. William Daniel Conybeare (1787–1857), a distinguished geologist and Dean of Llandaff wrote to Buckland saying, "Though sadly frostbitten at this moment, I don't believe in the former Geological Supremacy of the Frost King … The Glacial Theory has always appeared to me a glorious example of hasty, unphilosophical, and entirely insufficient induction" (8 November and 15 December 1840; North 1943, 4).

Figure 11 The 'Hotel des Neuchâtelois', located on the medial moraine of the Unteraar glacier and acting as base camp for the Agassiz glacier team for the 1840–2 field seasons (lithograph by J. Burckhardt).

5 Hotel des Neuchâteloises

Lengthy periods of study on the Swiss glaciers were physically demanding. In the early days of his investigations, Agassiz and his companions would commonly stay at the Grimsel Hospice on the margins of the Grimselsee, and walk to their localities each day. How much more convenient it would be to have a base on the glacier itself, much as their forerunner, alpine explorer and cartographer Franz Joseph Hugi (1791–1855) had done on the Aar Glacier in 1827! The only problem was that Hugi's hut now lay in ruins; a shelter of their own making was required. Agassiz was keen to establish his base on the medial moraine in the centre of the Unteraar Glacier, again close to the base of the Abschwung. An enormous block of mica schist with a natural southward-facing overhang was selected (Fig. 11) and, with the help of four porters from the Grimsel Hospice, the shelter was provisioned in readiness for habitation that same evening. A layer of grass and oilcloth was spread over the floor and a curtain spread at the entrance in order to lend a little comfort and civilised sobriety, while a rough wall of stones kept out the worst of the elements. Nocturnal discussions generated a name for the habitation, and 'Hotel des Neuchâteloises' was carved, together

with the names of the first six inhabitants, in large letters on a joint surface defining one face of the block (Fig. 12).

A daily routine established itself. Some incumbents bathed each morning in a tub of water placed in front of the door the previous evening; breaking the ice on the surface each morning was only a minor inconvenience! A breakfast drink of hot chocolate or cheese soup was prepared between 4 and 5 a.m. and, duly fed and watered, the party would divide up for the day in order to pursue their agreed tasks. Lunch at the 'Hotel' invariably consisted of mutton and rice, interspersed with occasional goat served *al fresco* on the block of gneiss that doubled as a table, and finished off with a cup of coffee and a post-prandial cigar (Williams 1854, 309).

The 'Hotel' was pleased to receive a series of visitors, some scientific and others who were family, friends and alpine walkers. During bad weather, rainwater penetrating the schistosity would drip onto the inhabitants from the ceiling, forcing them to move essential equipment, books, notes and bedding when strategies for deflecting the courses of the rivulets flowing over the rock surface failed. The 'Hotel', of course, was doomed to the same fate as Hugi's hut, being swept inexorably toward the toe of the Unteraar glacier on its bed of glacial moraine. Consequently it was useful for a few field seasons only; in 1842 it was abandoned in favour of tents erected on the solid bedrock forming the walls of the valley. Broken fragments of the 'Hotel', identifiable from the remains of their inscriptions, were still visible at the toe of the glacier in the 1920s (Gos 1928). Both the 'Hotel' and the tents served well as field stations providing convenient access to the Unteraar and adjacent glaciers, permitting the execution of a much more systematic approach to glacier study than had previously been attempted. Agassiz set up a detailed research protocol considering many interesting features of the glacier, including analysis of the transformation of snow into ice, the origin and occurrence of stratification and small-scale structures in the ice, overall glacier topography and cli-

Figure 12 The 'Hotel des Neuchâteloise', with the names of the research team and visitors carved on it (lithograph by F. Collomb).

mate, rates of movement, infiltration, rates of discharge from glacial streams, the significance of ablation and the detailed nature of moraines. Of the three planned volumes summarising the results of the research only Agassiz (1847) was eventually published.

One of the earliest attempts to measure rates of glacier movement was carried out by Monsieur Jond, a Chamonix guide and parish priest, resulting from a suggestion made by the French Minister at Geneva. On 3 November 1772, Jond planted a series

Figure 13 Detail from Agassiz's (1847) map of the Unteraar Glacier. Note the changing positions of blocks numbers 16, 17 and 18, just behind the glacier snout for successive years from 1843 to 1846.

of trees across the Mer de Glace; remarkably, the trees survived, and he was able to calculate that they had moved a distance of more than 4m over a full year. Agassiz employed an essentially similar approach. Using a more scientific methodology than his predecessor, Agassiz first observed the positions of wooden stakes driven into the ice across the entire span of the glacier, but later employed a local engineer to accurately triangulate the positions of 18 large boulders on the glacier surface. The boulders were carefully chosen to represent the full length and breadth of the glacier, and the reference points for the triangulations were prominent landmarks in the adjacent bedrock. The progress of the blocks was then tracked through four successive field seasons (1843–6) and the data subject to analysis. For example, Agassiz found that Block 5 located on the medial moraine close to the 'Hotel' was transported a total distance of more than 305m over a period of 1,450 days, giving a mean annual rate of movement of more than 77m. By contrast, Block 17, located just behind the snout of the glacier (Fig. 13), moved by an average of only 30m per year. By means of these data, Louis was able to show that the ice in the central part of the glacier moved more rapidly than that at the margins, a conclusion that was exactly the opposite of the prevailing opinion.

The engineer was also pressed into service in order to supervise the making of ice borings so that Agassiz could examine the internal structure of the glacier and calculate its total depth. Glacier innards, of course, are exposed in open fissures, which develop as the ice moves differentially and over uneven ground. The problem is that these are rather transient structures and, because the ice is constantly moving, dangerous to enter. On one occasion in the 1841 field season, the team came across a large open fissure, which Louis insisted on investigating first-hand. Working quickly in case the opportunity for exploration should be lost by the inexorable movement of the glacier, a tripod was erected and, despite voluble protestations by his companions, Louis was seated on a board, had his shoulders covered by a goat skin and wearing a marmot-skin cap, was duly lowered into the cleft by ropes suspended from the beams (Williams 1854, 303). At a depth of 24m, the fissure divided; Louis chose which channel to negotiate and was lowered farther. Captivated by the novelty of his surroundings, Louis was suddenly plunged into icy cold glacial water. His cries of distress and surprise were misinterpreted at the surface as a desire to go deeper — they let out the ropes accordingly. Renewed yelling brought the descent to a halt, and Louis was hauled back up through the fissure. This part of the exploration proved just as hazardous, for now Agassiz had to safely negotiate a succession of long, wickedly pointed ice stalactites!

Neither did the team neglect other branches of natural history. The glacier surface proved to be a playground for tiny insects called colloquially 'glacier fleas'. These are actually small collembolans or 'springtails', formerly referred to in the literature as 'podurelles'. Nicolet described a new form (Fig. 6, *above*), which he dubbed *Desoria glacialis* (now synonymised with *D. saltans*) after Agassiz's secretary, who found large numbers of them on the surface of the ice. Bearing in mind how much Cécile detested Desor as a social parasite blighting the Agassiz family it is interesting to speculate how she might have appreciated the irony of his lending his name to a 'flea'.

6 Ascent of the Jungfrau

At 4,158m (13,642ft), the Jungfrau is the highest peak in the Bernese Alps (Fig. 14). In those days of Alpine adventure, mountaineers were eager to be the first to climb progressively more inaccessible peaks. Hugi attempted ascents of the Jungfrau during 1828 and 1829, choosing a route across the Rottal, an ice-field to the south-west of the mountain. His lack of success may have been due either to ghostly interference from the 'Lords of Rottal' (spirits of predecessors who had met their deaths on the mountain), or to his lack of restraint when it came to limiting himself to essential equipment only (in addition to a huge array of scientific instruments, he insisted on taking boot blacking with him!).

Figure 15 Portrait of James David Forbes (1809–1868) from Shairp, Tait and Adams-Reilly (1873, frontispiece).

Louis invited James David Forbes (Fig. 15), the Edinburgh physicist and geologist, to stay with him at the 'Hotel' during the summer of 1841, so that they could study the ice together. As his visit drew to a close, it was suggested that a 'grand expedition' was in order: they would attempt an ascent of the Jungfrau. Rising early, they walked to the Oberaar Glacier, crossed over the Oberaarjoch at its head and thence down onto Galmig arm of the Fiescher Glacier to the huts at Marjelen. Crossing over to the mighty Aletsch Glacier (Fig. 16), they were to make their way up to the Jungfraufirn, and then up the steep rocky face of the Rottalsattel before following the ridge of the arête to the summit of the Jungfrau (Fig. 17, *opposite*).

This plan was all very well in theory, but a mishap cost them several hours of journey time. The party's guide, Jakob Leuthold (1807–1843) (Fig. 18, *opposite*), a wiry man with "a twinkling grey eye" (Forbes 1853, 303) had accompanied Hugi during his attempt on the Jungfrau nine years earlier. On that occasion, a ladder was used to negotiate the crevasses, and Leuthold had stowed it safely near one particular fissure. Fully expecting it to be where he had left it, despite the passage of time, Leuthold was insensed to learn from a local shepherd that the ladder had been removed some years earlier by a Viesch (now Fiesch) peasant. Sending an envoy several kilometers to the peasant's house to reclaim the ladder was to no avail. It was not until a second representation was made with threats of actual grievous bodily harm that the famous ladder was yielded. Then followed a demanding

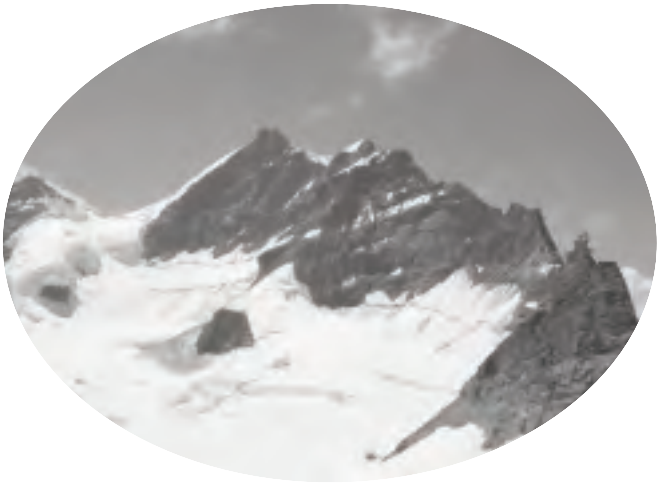


Figure 14 The Jungfrau in the Bernese Alps, photographed from the Jungfraufirn, north-east of the peak.

Figure 16 View across the Jungfraufirn to the Aletsch Glacier from the Jungfraujoch.

six hours of difficult walking, often over soft snow covering the ice and hiding the crevasses beneath.

The 7m-long ladder was put to good use while negotiating the crevasses and fissures in the ice and the party successfully reached the rocky base of the Rottal. One guide immediately turned tail at the sight of the steep slope before him, leaving the remainder of the party, fortified by a good quantity of wine, to proceed up the incline by means of cutting steps into the angled snowfield. The summit was reached at 4 p.m., although the small platform at the crest was large enough to accommodate only one person at a time. After a half hour's rest, recuperation, self-congratulation and admiration of the views, the party commenced the even more hair-raising descent, which involved retracing their steps by walking backwards down the slope (i.e. facing the mountain), eventually regaining habitation in the late evening after scrambling over crevasses by moonlight. Agassiz then had the party out of bed by 6 a.m. the next morning in order to continue with the adventure! Forbes had been suffering from a badly twisted ankle earlier in the week, but found that the ascent did wonders for the offending limb — the only problem now was that he was suffering from "a sharp inflammation of the eyes"; the sage advice of his doctor was to avoid glaciers for a while!

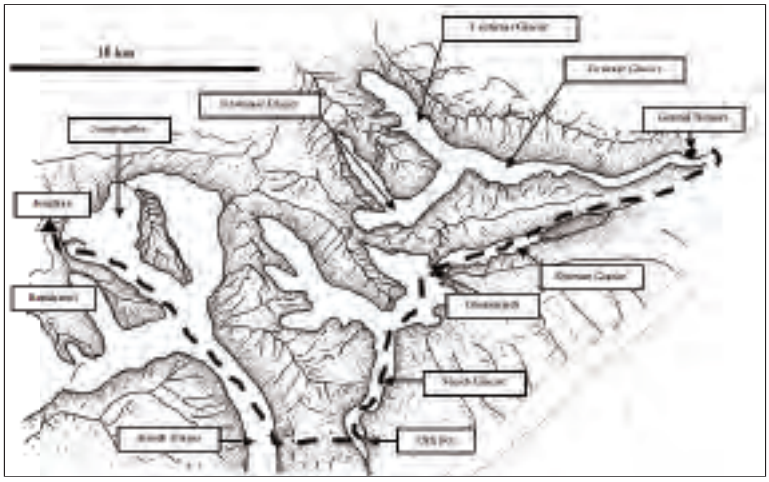


Figure 17 Reconstructed route taken by Agassiz, Forbes and companions in the ascent of the Jungfrau, August 1841.

7 Controversy

Agassiz's work on glaciers was not without its difficulties, so far as personal relationships were concerned. Engaging, friendly and enthusiastic, Louis was a charismatic character, but a certain naivety combined with at least questionable approaches to the publication of the research team's results lead him into conflict with his friends and colleagues. The questions of priority and due recognition were the twin themes that seemed to raise their hydra-like heads with surprising persistence throughout his career.

Figure 18 Portrait of Jakob Leuthold (1807–1843) by J. Burckhardt from Desor (1844, facing page 588).

In terms of his glacier work, his first real conflict was with Schimper, undisputed author of the term 'Ice Age'. The break between these two friends occurred in 1838 (Marcou 1896, I, 206) but rumbled on for years. Although fully acknowledged for his contributions in Agassiz's 'Discours' (1837), Schimper was not quoted in his later *Études sur les Glaciers* (1840) and so he began a war of attrition through a series of newspaper articles directing a range of accusations against Agassiz. Marcou's (1896) assessment of the situation is that Agassiz could have exercised more care and wisdom when giving due credit in his later work, but that Schimper was becoming progressively more unstable as time wore on. Indeed, he was eventually confined to an asylum at Schwetzingen, where he eventually died on 21 December 1867.

Relations also deteriorated with de Charpentier. Keen to share his insights with Agassiz, de Charpentier was slow to publish his ideas. In a short paper read before the Société Helvétique des Sciences Naturelles in 1834, and subsequently published in 1835, de Charpentier showed that Swiss erratics were most probably transported to their current locations by means of glaciers. Agassiz opposed that thesis at the time (Marcou 1896, I, 73). Having embraced de Charpentier's evidence wholeheartedly in 1836, Agassiz then persistently encouraged his friend to publish a broader and fuller account of his conclusions. De Charpentier responded and wrote his 'Essai sur les glaciers' (1841). The problem was that Agassiz, a man of impulsive, prodigious and rapid literary output, had completed his *Études sur les Glaciers* already. Indeed, de Charpentier received a complimentary copy from Agassiz three days before he placed the final full stop on his own manuscript. De Charpentier was aggrieved; he considered that, as a matter of polite sportsmanship, the student should have waited for the teacher to complete his work first. Marcou (1896, I, 163) observes that, by this time, Agassiz was "already too much influenced by his secretary and by some others of his collaborators, more or less interested in keeping matters embroiled".

The pernicious influence of Desor was also an important factor in Agassiz's acrimonious and very public dispute with Forbes over the laws regulating the movements of glaciers, and the recognition of 'blue bands' in the ice. These blue bands consisted of fine, parallel alternating strata of blue and white ice extending vertically to depths of at least 6m in the glacier (Forbes diary entry, Monday 9 August 1841; quoted in Campbell and Hutchinson 1978, 390). On coming across a published letter from Agassiz to Humboldt in October of the same year, describing the nature and identifying the importance of the bands, Forbes saw this as 'open academic piracy' (Campbell and Hutchinson 1978, 391). A series of arguments and counterclaims was then published in a sequence of open letters. As both men became privately more and more offended, Desor stoked the fire with some objectionable letters to Forbes. From that point on, the relationship deteriorated steadily (Campbell and Hutchinson 1978; Cunningham 1990).

8 Glaciation in the USA

In 1846, an opportunity arose to visit the USA. Intended to be only temporary, supported by the King of Prussia and with specific aims, Agassiz ended up staying there for the rest of his life, returning to Europe only once more. The timing of the trip was fortuitous; Agassiz's publishing activities were running into financial difficulties, Cécile had returned to Karlsruhe with Alexander and Louis was becoming increasingly depressed.

Travelling to Liverpool via Paris, so that he could complete the final negotiations with the Masson publishing house for his forthcoming report on the summer field seasons on the Aar glaciers (Agassiz 1847), Louis took a berth on Cunard's regular transatlantic passenger service on the *Hibernia*. On alighting at Halifax, Nova Scotia, Agassiz "sprang on shore and started at a brisk pace for the heights above the landing. On the first undisturbed ground, after leaving the town, I was met by the familiar signs, the polished surfaces, the furrows and scratches … and I became convinced of what I had already anticipated as the logical sequence of my previous investigations, that here also, this great agent had been at work" (Agassiz 1885, 445–6).

Soon ensconced in Boston, Agassiz was quickly convinced to make the USA his new home. Here was an adoring public with a thirst for knowledge and a heart as large as the continent itself. Somewhat embarrassed by his then limited English, he was permitted to deliver his first series of lectures on glaciers and the Ice Age ('Les glaciers et l'époque glaciaire') in French (Carozzi 1966, 80). Distracted anew by the enticements of the more or less virgin natural history now available to him, glacial studies became relegated to a lower priority. Nevertheless, a visit to Niagara falls in 1847 yielded not only spectacular scenery, but clear evidence of past glaciation. In fact, almost everywhere he went pursuing his sightseeing and zoological studies – New York, Maine, New England and the environs of Lake Superior – all provided clear evidence of 'God's great plough' as he called it (Agassiz 1876, 99).

Thoroughly occupied by his ambitions to describe the zoology of an entire hemisphere, amass a comprehensive collection of specimens from every corner of the USA and house them in a permanent museum, Agassiz had to leave the business of the description and analysis of glacial features to the emerging generation of native geologists (see, for example, White 1967, Aber 1984), mostly working from Hitchcock's digest of Agassiz's work (Hitchcock 1841). Nevertheless, his popular lecture series continued (Dexter 1989), many accounts being published as a series in Atlantic Monthly (1863–4), and some included in a later collection of essays (Agassiz 1876).

An excursion to Maine in September 1864 seemed to re-energise his interests in glaciology — polished rocks, glacial striae, drift deposits, erratic blocks (which he called 'the wandering Bohemians' of the geological world; Agassiz 1876, 102), *roches moutonnées* and winding, linear ridges colloquially called 'horsebacks' (Agassiz 1885, 622) all testified to extensive glaciation over a massive area east of the Rockies. In spite of all this evidence to the contrary, Agassiz was incredulous that even in 1867, "If not openly said, it is whispered, that, after all, this great ice-period is a mere fancy, worthy at best of a place among the tales of the Arabian Nights". Yet to Agassiz himself, "the presence of the ice is now an unimportant element to me in the study of glacial phenomena; no more essential than is the flesh to the anatomist who studies the skeleton of a fossil animal" (Agassiz 1885, 623); the signs of drift deposits, striated pavements and erratic blocks were all that he needed to conjure up a vision of a land covered in ice.

9 South America

By 1864, Louis's occasional bouts of ill health were becoming more persistent. During the last Lowell lecture of the winter 1864–5 series, Agassiz appealed to global glaciation as a means of disproving Darwin's despised theory of evolution (Lurie 1988, 345); if the advance of continental ice sheets had destroyed all life before them in a final Cuvieran revolution, then there could be no genetic continuity between the animals of the present and the past. In the previous year, Charles Lyell had published evidence in support of a southward faunal migration toward tropical refugia in response to extensive glaciation in the northern hemisphere (Lyell 1863). Agassiz pointed to South America and Brazil in particular as the place to look for evidence of glacial equatorial encroachment. What was needed was for a competent naturalist to examine the Andes mountains and Brazil in search of the evidence of glacial activity.

Nathaniel Thayer (1808–1883), a wealthy Bostonian businessman and Trustee of Agassiz's Museum of Comparative Zoology at Harvard, concerned over Agassiz's health, agreed to underwrite such a venture. Louis leapt at the opportunity and, typically for him, began to expand the concept dramatically. His first ever publication described the collection of Amazon fishes made by the Germans Spix and von Martius earlier in the century; here, in addition to the search for evidences of glaciation, was an opportunity to collect from each of the distributaries of the mighty river. The expedition personnel included Louis's wife, Bostonian Elizabeth Cary Agassiz, 1822–1907 (Cécile had died of tuberculosis in Germany in 1846, and Agassiz had remarried on 25 April 1850), and a number of young assistants, including two geologists: Orestes Hawley St John (1841–1921; later a prolific contributor to various geological surveys) and Charles Frederick Hartt (1840–1878; who subsequently set up the Imperial Geological Commission in Brazil) (Fig. 19).

Figure 19 Portrait of Charles Frederick Hartt, reproduced through the kind permission of W. R. Brice and the Earth and Atmospheric Sciences and Division of Rare and Manuscript Collections, Kroch Library, Cornell University, Ithaca, New York, USA.

Leaving New York on 1 April 1865 on the steamship *Colorado*, the party was away for a period of 16 months. Evening entertainment on the outward voyage comprised a series of lectures given by an already revitalised Agassiz. His address after only a week at sea (9 April 1865) returned to the topic of global glaciation. He stated, "I am as confident that we shall find these indications at about the limit I have pointed out as if I had already seen them" (Agassiz and Agassiz 1868, 19), while speculating on the southern extension of glaciers to a latitude of 36º N. Docking at Rio de Janeiro on 23 April, the party was warmly received by the Emperor, Dom Pedro II (1825–1891) who even placed a Brazilian warship at their disposal.

At Tijuca, a long ramble by Agassiz on 26 May yielded the evi-

dence that he was looking for. The rocks they had seen up to that point had been difficult to interpret. There was much highly decomposed superficial material, often sculpted into fantastic shapes and only loosely consolidated. Yet now, confined to his hotel by heavy rain, Agassiz was able to write excitedly to his friend, Harvard mathematician Dr Benjamin Peirce (1809–1880), "Yesterday was one of the happiest days of my life … from the terrace … you see a drift hill with innumerable erratic boulders, as characteristic as any I have seen in New England" (Agassiz and Agassiz 1868, 86–8). Almost everywhere he went along the Brazilian coast, and even inland, where exposure permitted, Agassiz saw the same sheet-like blanket of red clayey matrix housing a mixture of pebbles and larger boulders. On 23 July, Major Coutinho of the government engineers corps joined the party for their investigations of the Amazon on the *Cruzeiro do Sul* (Agassiz and Agassiz 1868, 122). The two got on very well together and on 20 August, Agassiz wrote to the Emperor saying that, "Now that Major Couthino has learned to distinguish the drift from the decomposed rocks, he assures me that we will find it throughout the valley of the Amazons" (Agassiz and Agassiz 1868, 150); indeed, the two wrote a joint paper to that effect (Agassiz and Coutinho 1868). Agassiz was satisfied that he had amassed sufficient evidence to prove the existence of a geological winter of cosmic proportions. Alfred Russell Wallace's (1823–1913) assessment was that this was "truly a startling conclusion, and one which has hitherto been received in this country with some incredulity. Prof. Agassiz was thought to be glacier-mad" (Wallace 1870, 510).

Neither was Hartt, Agassiz's student, so easily convinced. He confessed to having considerable difficulty when it came to distinguishing between drift and deeply weathered material in the field. So far as he was concerned, two additional corroborating proofs were lacking: where were the glacial striae and polished rock surfaces so typical of glacial features in Europe and the USA? Agassiz responded by providing the answer that deep weathering had obliterated all sign of them.

On returning to Boston, Agassiz set about publishing the results of the expedition together with his wife (Agassiz and Agassiz 1868), and incorporated the newly collected proofs of global glaciation into his popular lecture series at the Lowell Institute. Hartt subsequently made several further visits to Brazil (1867, 1870, 1871 and 1874) and found himself becoming increasingly persuaded that weathering was the cause of these 'drift' deposits and not glacial activity (Brice and Figueiroa 2003, 18). In his book describing the geological results of the expedition (Hartt and Agassiz 1870), Hartt could work up little enthusiasm for Agassiz's conclusions, and carefully presented alternative explanations. He did not accept Agassiz's suggestion of the former existence of an enormous Amazonian glacier. These suspicions developed at a most inopportune time for Hartt; Agassiz was recommending him for the first professorship in Geology at Cornell University — not the most auspicious time to disagree with your mentor! Time has vindicated Hartt's views, however, and while there is evidence of glaciation in the South American Palaeozoic record, there is no evidence of Pleistocene glaciers scouring the Amazonian landscape. Hartt's student, John C. Branner (1850–1922) continued his teacher's studies to the end of the century (Branner 1893), and an erstwhile anxious Alfred Wallace expressed his gratitude to the pair for relieving science of "a true glacial nightmare" (Wallace 1893, 590) — how to best explain large-scale glaciation close to sea level in the tropics. Agassiz, perhaps remembering the pain of his earlier altercation with Forbes, declined to become embroiled in a public argument over the matter.

Conclusions

Agassiz's last excursion of any substance to view glacial phenomena took place after his return to the USA from his voyage to Brazil. He was invited to join a party including 'tired congressmen' (Agassiz 1885, 661) on a trip out West on the Union Pacific railroad. Here, in a region new to him, he observed ground moraines and grooved bedrock, and, keeping his view of extensive glaciation in the western hemisphere alive, wrote to his old friend, Auguste de la Rive (1801–1873), the famous Swiss physicist, "We have to do first with sheets of ice, five or six thousand feet in thickness … covering the whole continent" (Agassiz 1885, 665).

Despite mistaken conclusions in many areas of his research, including his glacial studies, Louis Agassiz is nevertheless appreciated as a scientist of bold vision, untiring zeal and naked intellectual passion for a panoply of geological and zoological topics. Indeed, his work was fundamental to the science of glaciology, a discipline that now supports the publication of a wide range of journals. At his death, the man who introduced the world to the idea of glaciers covering the bulk of north-west Europe received a fitting memorial: his Boston grave is marked by a 1,100kg boulder shipped from his beloved Aar glacier, and surrounded by a stand of specially planted Swiss pine trees (Fig. 20). As his wife remarked in the closing sentence of her biography of Louis Agassiz, "The land of his birth and the land of his adoption are united in his grave" (Agassiz 1885, 783).

Figure 20 Boulder from the Aar Glacier marking Louis Agassiz's grave at Montaubon Cemetry, Boston, Massachusetts, USA: (a) front view, (b) rear view (courtesy of David Stahl).

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Jackson, A. A. 2008 *British Geological Survey, Bedrock Geology UK South: an explanation of the bedrock geology map of England and Wales* (1:625 000) (5 edn). Keyworth: British Geological Survey (ISBN 978 085272 585 3; guide and map, 84pp; £15 or £10 (guide only)

This 5th edition Bedrock Geology is strikingly different from the previous editions. When I studied S260 I bought the Geological Survey 10 mile map, 3rd edition, replacing one I lost with a 4th edition several years later. This has given me two editions with which to make comparisons.

The new edition has been compiled from a new digital database of 1:50 000 geological map data. Along with each of the maps — in glorious new colours — is an explanatory guide. These companion booklets describe the different rock units that lie beneath the surface and give a brief explanation of their origins. The two maps cover the whole of the UK with most of Northern England (including the Lake District) appearing on both maps. The increased coverage, through an extra 80mm on both dimensions, ensures that the North sheet includes all of Northern Ireland. Each map contains an index and explanation, cross sections that give a general relationship of the bedrock at depth and a brief description of the contents.

The colours have evolved over the three editions, with some units retaining their original colours, chalk is green and Mg limestone is blue. The map code has changed from numbers to an alpha numeric code, which reflects the period: e.g. C for Carboniferous. More details have been added to show faults and relative movement in the bedrock, with some major faults being named and referred to in the accompanying guide.

The books have an introduction in common, including: 'A geological timescale', 'A brief history of the map', 'What the map shows' and an outline of tectonic processes with a series of figures showing the reconstruction of the position of landmasses over time.

The remaining chapters describe the rocks from oldest to youngest and are colour indexed to the geological timescale. Each chapter starts with a general description of tectonic history for the period with a small inset map to show the distribution of the rock laid down in this time. It goes on to give more details of each of the major rocks within the succession, including a variety of illustrations of rocks and landforms, sketch maps and diagrams of palaogeographical and lithographical features. There are also blocks between the chapters that outline tectonic cycles and how the different orogenies have affected the region.

There is a lot to explore using both maps and guides. The map is good to look at and the new map code enables one to identify the age of rocks more easily. It is necessary to have some prior experience of geological terminology to gain the full benefit from the guides.

— Averil Leaver Cert Ed., continuing OU Earth Sciences student

Map review

Hopson, P. M., Farrant, A. R., Newell, A. J., Marks, R. J., Booth, K. A., Bateson, L. B., Woods, M. A., Wilkinson, I. P., Brayson, J. and Evans, D. J. 2007 [book] *Geology of the Salisbury District: sheet explanation* and 2005 [map] *British Geological Survey sheet 298* (1:50 000). Keyworth: British Geological Survey (ISBN 978 085272 543 6 [book] and 978 075183 425 3 [map]; map and book, 38pp; £18)

The authors have written a simple, clear description of the surface and concealed geology of the Salisbury area, together with its structure and present-day landforms. Boreholes have provided an overview of Cambrian to middle Jurassic strata. The outcrop commences with the Kimmeridge Clay, and the upper Jurassic, Cretaceous, Palaeogene and Quaternary are each identified.

The correlation tables are a crucial and informative part of the book, as names of strata have changed considerably both over the last 100 years of study and between the publication of the Bournemouth and Shaftesbury Memoirs and the subsequent Ringwood and Salisbury 'brief explanations'. There are a few photographs, mainly of Chalk, but then that is the most widespread of the geological Formations.

Applied geology includes hydrogeology, soils, building stone, bulk minerals, hydrocarbons and geological hazards. The most famous building stone is from the Portland Group, which provided stone for Salisbury Cathedral.

The information sources and references can be consulted to find greater detail, but I personally am very disappointed that the practice of compiling memoirs such as those for Bournemouth and Shaftesbury has been discontinued.

— Jo Thomas BA (Hons) OU

Nineteenth-century battles over bones and ice: Geikie versus Dawkins

Dr Anne O'Connor (Honorary Research Fellow, Department of Archaeology, Durham University)

Introduction

In this paper I am going to give a brief overview of what I consider to be a very interesting topic in the history of geology: the problems experienced by geologists during the late 19th century as they tried to construct a timescale for the Quaternary in Britain. It was an immensely difficult problem to organise into any coherent order the varied sediments and bones that were scattered across the country, and to find a logical sequence that they could agree on. I will be focusing on the arguments that peaked in 1881 between James Geikie and William Boyd Dawkins to illustrate the complexity of this problem and the logic behind some of the different solutions that were put forward.

The argument of 1881

1881 was a tense year for James Geikie. He had just published his book *Prehistoric Europe: a geological sketch*, in which he had summarized the climatic and geographical changes that had affected the Continent in Quaternary times (Geikie 1881a). The first reviews were coming out. One of these appeared in the February edition of *Nature*, a most prestigious journal. It had been written by William Boyd Dawkins and was extremely critical. *Nature* had a wide circulation, so this was bad publicity for Geikie and his book.

In essence, Dawkins' main reasons for disliking the book were: first, its emphasis on glacial geology as the key to revealing Britain's geological sequence; and second, its support for interglacial episodes. Dawkins wrote: "Dr James Geikie takes his stand upon the glaciated mountains of Scotland, and attempts to throw the glacial net woven in his previous work, 'The Ice Age', over the whole of Europe" (Dawkins 1881a, 309).

Geikie responded by writing a letter of reply. Soon afterwards, Dawkins would have read in *Nature* that Geikie had rejected his suggestion that *Prehistoric Europe* was based too heavily on ice classifications. Moreover, Geikie threw a similar criticism back at Dawkins, writing: "Geologists rightly refuse to accept classifications which are based upon so narrow a foundation as a single series of phenomena, such, for example, as Mr. Dawkins' attempt to classify the Pleistocene by reference to the mammalia alone" (Geikie 1881b).

So while Geikie favoured ice and glacial theories, Dawkins focused on bones and palaeontology to summarise the sequence of Quaternary deposits in Britain; they both reached conflicting conclusions. Their disagreement had been festering for some time, according to a private letter written by Geikie to a friend on the Geological Survey, in which he traced several earlier, anonymous attacks to Dawkins, and disparaged Dawkins' expertise in physical geology (Geikie to Peach, 17 February 1881).

Dawkins and Geikie

The battle of 1881 can be understood better after tracing the backgrounds of these two protagonists. At the time, Dawkins (1837–1929) was Professor of Geology at Owen's College, Manchester. Around two decades earlier, during the 1860s, he had worked as an officer on the British Geological Survey, helping to map the Thames Valley in the London District. However, Dawkins soon become better known for his palaeontological research into mammal bones from caves and the rich Thames Valley deposits. He presented his results in a series of detailed papers through the 1860s and 1870s, promoting the same general idea (Dawkins 1869; 1872). Much simplified, Dawkins' theory ran something like this: after a warm start when Britain was colonised by warmth-loving mammals such as hippopotamus, the temperature dropped steadily throughout the Quaternary, and cold-loving species like reindeer began to invade Britain. Dawkins placed these mammal species into different groups, splitting the Quaternary into successive, mammal-based divisions. In 1880, the year before he reviewed Geikie's book, Dawkins had published his own book, *Early Man in Britain*, in which he promoted this mammalian classification of the Quaternary (Dawkins 1880). He had made similar suggestions in an earlier book, *Cave Hunting* (Dawkins 1874).

James Geikie (1839–1915) had also spent his formative years on the Geological Survey. In 1861, he ended an unhappy apprenticeship to a printer in order to join the Survey's Scottish branch, where his more famous brother, Archibald, was already working. James was the more popular of the two. He enjoyed the outdoor life and became intrigued by the problems of mapping the Scottish glacial drifts. In the early 1870s he published his first detailed account of ancient climatic change in the *Geological Magazine* in a series of papers entitled 'On changes of climate during the glacial epoch' (Geikie 1871; 1872). Geikie argued that Britain had experienced a sequence of lengthy glacial and interglacial cycles over the Quaternary period. Soon afterwards, he elaborated on these papers in a book: *The Great Ice Age* (Geikie 1874). Geikie's pattern of alternating warm interglacial and cold glacial periods was fundamentally different from Dawkins' gradual onset of cold, and they were soon disagreeing with each other.

Quaternary geology in the later 19th century: a (very) brief overview

Before going into more detail about their conflicting views, I will summarize some of the more important theories of Quaternary geology during the later 19th century. Research into the recent geological past — the deposits known as 'superficial' geology or 'drift' — had lagged behind the heroic age of research into the older, solid geology. William Whitaker, who came to be one of the Geological Survey's most enthusiastic mappers of Quaternary stratigraphy during the second half of the 19th century, described how: "The older geologists treated all Drift as of one kind, and did not trouble themselves about such perplexing matters as its divisions and their classification. They accepted this varying set of deposits rather as a necessary evil, obscuring the beds below" (Whitaker 1889 (i), 353).

Interest in the Quaternary had increased after Joseph Prestwich, a wine merchant, published papers in the early 1860s on the sequences of deposits in the river valleys of the Somme and of the Thames (Prestwich 1860). The Survey added further details to Prestwich's theories that same decade after they began mapping drift in the London District (assisted by Dawkins as well as by

OUGS Journal 29 (2) Symposium Edition 2008, 66–9
© OUGS ISSN 0143-9472

Whitaker) and in East Anglia (helped by the private researches of Searles V. Wood Jr). These two geographical areas came to dominate Quaternary studies: the Thames Valley with its lengthy sequence of river gravels and brickearths rich in bones; and East Anglia, to the north, with its complicated series of glacial deposits known as glacial drifts or boulder clays.

One pervasive theory of the 19th century was the concept of a mid-glacial submergence: the idea that part way through the Quaternary, also known as the Glacial Epoch, the land had sunk beneath the sea, and then emerged again. This episode was seen as a crucial marker-point dividing pre-glacial from post-glacial times. One particular deposit, the Chalky Boulder Clay of East Anglia, was regarded as a most distinctive reflection of this time of submergence. It appeared that the river drifts of the Thames Valley, and the Quaternary cave sediments scattered in isolated pockets across England and Wales, post-dated the submergence. By the 1860s and 1870s, such river drifts and caves were regularly described as post-glacial in date — 'post-glacial' generally meaning post-submergence and post-Chalky Boulder Clay of East Anglia.

But it was difficult to mesh the pattern of mammal species to the idea of a gradually cooling glacial epoch, albeit interrupted by this mid-glacial submergence. In the supposedly 'post-glacial' deposits of the Thames Valley and the caves, geologists had found a *mixture* of cold-loving species and warmth-loving species. This mixed fauna was a puzzle: it would have been much neater if all the post-glacial species, late in Quaternary time, had been cold-loving, arctic types that would match the idea of a gradual decrease in temperature. Prestwich wondered whether hippo had adapted to cold, post-glacial conditions by growing warm, furry coats (Prestwich 1864, 285). Charles Lyell got round the problem by suggesting that hippos had followed seasonal migration routes, basking in the Thames during the summer and retreating south in the icy winter (Lyell 1863, 156, 180–1). Dawkins adopted this seasonal migration theory as his own; it helped to keep his faunal classification intact. But Geikie preferred an alternative explanation for mixed fauna, one that had been put forward by James Croll.

Croll had trained as a millwright in Scotland, but suffered ill health. He developed an interest in physics and astronomy while working at Anderson's College and Museum in Glasgow, helped by their library of books. Croll published several papers on how the changing orbit of the earth had caused climatic changes in the past (Croll 1864; 1875). His talents were recognised, and he was offered the post of Secretary on the Scottish Survey. Geikie probably met him in the late 1860s when it was too cold in the field, and the surveyors gathered in Edinburgh to do office work.

It was about that time that Croll put forward his idea that the climate had *fluctuated* during the Glacial Epoch. Instead of annual changes with the seasons, and hippos moving north and south each year, Croll envisaged several lengthy, alternating glacial and interglacial periods. Warm fauna colonised Britain during warm interglacials, and cold fauna in glacials. Their bones had been mixed together by the glaciers that scoured the land surface during each successive glacial period.

Geikie developed Croll's ideas (with due acknowledgement) in his book, *The Great Ice Age*. The same assumptions of long-term climatic fluctuation underpinned his descriptions in *Prehistoric Europe*, the book that Dawkins disapproved of so vehemently in 1881. Geikie still recognised a mid-glacial submergence, but he also described several advances of land ice on each side of this old boundary, before and after, including later glaciation in north England.

This meant that while most of Geikie's fellow geologists, particularly those in southern England, recognised one important glacial marker — the Chalky Boulder Clay of East Anglia — Geikie saw this as one of *several* glacial deposits, left by different glacial periods. So while his peers described the Thames Valley drifts as post-glacial because they post-dated the local, East Anglian boulder clay, Geikie regarded these drifts as interglacial because he recognised both older and younger boulder clays, taking the whole of Britain into account. This fundamental difference in perspective and terminology made it difficult for him to win many supporters. One of his contemporaries explained the problem thus: "The Thames-Valley Deposits are no doubt later than the Chalky Boulder Clay, and are considered Post-Glacial in the sense of being newer than the latest glacial deposits in the district; but they are Interglacial if we include in the Glacial Epoch the later evidences of ice-action in North Britain" (Woodward 1886, 129).

The argument of 1881: why did it happen?

Returning to the argument of 1881, it is now easier to understand why this happened. The theories of Geikie and Dawkins clashed significantly in their content: to reiterate, while Dawkins believed that Britain's mammals had undertaken rapid, seasonal migrations, thus explaining the curious mix of warm and cold fauna, Geikie thought that these palaeontological patterns were better explained by a series of lengthy glacial and interglacial periods, with warm fauna persisting for millennia rather than only for seasons. Cold fauna, in Geikie's view, had replaced warm fauna gradually when the climate changed, and the bones of the two groups had been stirred up together by the disruptive glaciers of each glacial episode.

Personal feelings about these contradictory perspectives on Quaternary time had been stirred up further by the explicit attacks each made on the other's theory in their respective books. Indeed, Geikie was surprised that Dawkins had been allowed to review *Prehistoric Europe* in the first place, since Dawkins' bias against him was so well known. The geological editor of *Nature* who let the review through turned out to be his (Geikie's) own brother, Archibald, which must have been another shock (Geikie to Ramsay, 27 February 1881).

The underlying reasons for their disagreement stemmed from fundamental differences of perspective, but they were also fuelled by the simple dislike of backing down, of admitting error: the need to retain dignity and prestige. It was important for Dawkins in particular to squash Geikie's book because it threatened his own theories. In the wider context of 19th-century geology, Geikie was defending an unpopular view of Quaternary times. Very few did agree with him. But it was not unexpected that the most inflammatory review came from Dawkins.

Dawkins was best known for his mammalian classification of Quaternary times, which he published repeatedly in slightly different versions, adding increasingly confusing migration patterns to reconcile each new discovery of bones to his original vision. This classification could not be adapted easily to Geikie's alternating climate, but it had been the foundation of his rather shaky status among geologists. Some letters suggest that Dawkins was not particularly respected as a surveyor among stratigraphical

experts such as Wood and Whitaker, who thought that Dawkins had not got to grips with the stratigraphical dovetailing in the Thames Valley (Wood to Harmer, 11 and 13 January 1867). Such opinions may have stimulated his drive to build a good reputation as a palaeontologist.

The content and tone of the 1881 argument between Geikie and Dawkins had been forged, in part, by the variety of different approaches to Quaternary geology. Dawkins thought that Geikie's wrong-headedness stemmed from an over-reliance on ice and glacial geology as the key to the Quaternary sequence. In Dawkins' view, the glaciers only reflected local conditions, so were a pretty useless indicator of broad-scale climatic change. For him, the fauna provided a far better basis for constructing a Quaternary timescale. Geikie countered this attack with similar criticism: that Dawkins was too reliant on the bones, and that glacial and interglacial cycles had a much more fundamental effect, not just in Britain but across Europe, and that climate change was the key to link up scattered geological sediments and shifting, varied mammal species.

What happened next?

So what happened next? Dawkins and Geikie continued their arguments in a series of further letters published in *Nature* (Dawkins 1881b; Geikie 1881b; 1881c). Geikie felt the attack deeply and was determined to fight it out, despite attempts by the editor of *Nature* to suppress his replies (Geikie to Ramsay, 27 February 1881; Geikie to Horne, 1881, quoted in Newbigin and Flett 1917, 94). They never resolved their disagreement. Both continued to elaborate upon their old theories throughout the 19th century, and well into the 20th (Dawkins 1910; Geikie 1894; 1914). Geikie became Professor of Geology at Edinburgh in 1882, but never gained much support for his glacialist views. Although a glacial–interglacial chronology would come to dominate the Quaternary chronologies developed by 20th-century geologists in Britain, these would be inspired by the Alpine sequence of German geologists Penck and Brückner. But it was to Geikie that Penck and Brückner dedicated their greatest publication on the subject (Penck and Brückner 1901–09).

What does this argument tell us about the history of geology?

Finally, what does this episode show us about the history of geology? I have described two irreconcilable visions of Britain during Quaternary times, and suggested that these reflect differences in background, geological interests and perspectives. Geikie and Dawkins themselves noticed that disagreements about geology could often be linked to experiences of different geographical regions (Geikie 1874, 355–6; Dawkins 1878, 159–60). It was not surprising that geologists clashed over the best way to build a chronology for the Quaternary period in Britain working, as they did, on sequences derived from different regions and on data as varied as glacial geology, palaeontology or river-drift stratigraphy.

Looking beyond the argument of Dawkins and Geikie to the opinions of Geikie's southern contemporaries, many failed to express an opinion on Dawkins' palaeontology, and some doubted his abilities as a stratigrapher, but most also failed to comprehend Geikie's perspective. They were used to regarding their local Chalky Boulder Clay in East Anglia as the most significant reflection of a pre-glacial submergence dividing pre-glacial from post-glacial times. For them, the Thames Valley had to be described as post-glacial because it post-dated that particular boulder clay. The boulder clay deposits that formed only a small part of Geikie's far grander geographical scheme filled the vision of many prestigious fellow geologists who lived near London, and its influential cluster of learned metropolitan societies, where they could publicise their views.

To return finally to Geikie and Dawkins: each immersed in their own perspective, they genuinely believed that the other had failed to appreciate the significance and scope of the alternative viewpoint; that the other had over-emphasised the importance of their own field of research, which was, in fact, rather narrow and could not account for half the data generated by the alternative, preferred field, be that glacial geology, palaeontology or stratigraphy. Sound familiar? The fundamentals of academic argument seem to change very little. I think the history of geology is interesting for its own sake, but if it has to teach us anything further, perhaps that should be the importance of retaining a sense of perspective.

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Book review

Wyse Jackson, Patrick N. (ed) 2007 *Four Centuries of Geological Travel: The Search for Knowledge on Foot, Bicycle, Sledge and Cam*el. London: The Geological Society (ISBN 978 1 86239 234 2; hardback, 415pp; £90)

In the modern world of fast, easy, global travel and instant communications it can be difficult to imagine a time when travel, particularly to a foreign country, required a great deal of organisation, and that a journey could last for weeks, if not months. *Four Centuries of Geological Travel* documents the travels of pioneering geologists as they searched for economically important minerals or simply journeyed to satisfy their own intellectual curiosities.

The book comprises 28 contributions from a symposium held in Dublin in July 2003 and traces the growth of geology as a science from the 17th to the early 20th century. The travel journals and sketches in which the pioneering geologists recorded their thoughts and observations give an insight into the immense difficulties and, in some cases dangers, faced by many of the travellers. Modes of transport range from walking, to bicycling in Ireland and Europe, to travel by canoe and sledge in Canada, by ship to the Cape Verde Islands and South America, and by camel in the Sahara.

Four Centuries of Geological Travel will fascinate those interested in the history of science, as well in the lives of the earth scientists themselves; also readers who like books about travel and exploration. However, priced at £90, it is possibly rather too expensive for the average reader.

— Lesley Laws BA

Book review

Thomas, Jo 2008 *Dorset Stone*. The Dovecote Press (ISBN 978 1 90434 963 1; paperback, 128pp); £17.95)

This well illustrated book is the result of many years of painstaking research. Using her knowledge gained from a first-class honours Geology and Science Degree from the OU, Jo Thomas set about collecting data from her local area. This became so interesting that her area eventually covered the whole of Dorset.

The first chapter gives an overview of the subject, the use of building stones in Dorset, the geological history of those stones and the history of its quarrying and transport. This is interesting enough to whet your appetite for what follows.

There then follows the main subject of the book: eight chapters dealing in detail with the stones. Starting at the bottom of the geological sequence in Dorset, the Lias, Thomas works her way up the sequence through the Inferior Oolite, the Forest Marble and Cornbrash, the Corallian Limestones, the Portland Freestone, the Purbeck Limestones, the Cretaceous and finishes with the Tertiary Heathstone.

Each chapter starts with a description of the depositional environment of the stone in question, the geological history and a description of the beds themselves. The use of each stone is described and examples quoted, accompanied by superb photographs of the buildings themselves and often a close-up of the stones. Maps of the outcrops, the quarries and also sometimes the parishes are also included.

Not content with just describing buildings, Thomas also embarks on a fascinating chapter on the stone bridges of the Stour Valley. Each bridge is described in great detail, attention being paid to the specific use of each stone, whether or not it was suitable for underwater use or otherwise. Dorset bridges are famous and Thomas's superb photographs do them justice.

The final chapter covers, appropriately, brick-making, as there are a lot of clay outcrops in the area covered. Some buildings are a mixture of stone and brick, used to great advantage in appearance.

Finally there is a table of 'Building Stone by Parish', enabling the reader to locate which stone is prevalent in each location; OS references are given.

Even if you do not live in Dorset and have never visited it, this book is fascinating and well worth a read. I certainly have a copy on my bookshelf.

— Jane Clarke MPhil (Open)

Making the invisible visible: early data display in the geological sciences

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Abstract

The representation of numerical results in the form of a graph or thematic map rather than in tabular form is today commonplace, in the earth sciences as elsewhere, so it is hard to conceive that until about 1860 numerical results in geological publications were presented almost exclusively in tabular form, even by the leading scientists of the day. With the apparent exception of isoline ('contour') and point-symbol maps, frequency polygons, and the multivariate graphic symbols introduced by geochemists in 1897–1900, most graphical display methods now used in the earth sciences came from outside the field. Leading proponents of 'the graphic method' are briefly described and the origins of the stereographic projection, line graphs, time series plots, rose-diagrams, the ternary diagram and multivariate symbols are discussed. Following the introduction of computers into universities (initially in the USA) after 1945, the time taken before earth scientists adopted new graphical methods was reduced abruptly.

Introduction: the rise of the graphical method

A graph is a pictorial data display, which today we take for granted; traditionally, it was something that was either hand-drawn or printed in ink in a journal or book in order to display numerical information in a way that enabled it to be assimilated easily and rapidly, and thereby effectively interpreted. Today graphs of all kinds are found in newspapers, and on the television news (often embellished by what the American student of graphics, Edward Tufte (1983, 107–23), has described as 'chart junk'), as well as in scientific journals. It is perhaps surprising to realise that although a very small number of scientists and mathematicians used the graphical method in the 17th century, even at the beginning of the 19th century such techniques were only rarely used, and most observational data was still being presented for interpretation in tabular form. Curiously, it took a long time before people realised that if you make pictorial displays of data values, then it makes their relationships more obvious, and hence their interpretation much easier.

The foundations were laid by the introduction of the Cartesian co-ordinate system by the influential French philosopher and mathematician, René Descartes (1596–1650), also known by the latinised form of his name, Renatus Cartesius, in his philosophical treatise on the natural sciences (Descartes 1637), in which he laid down the principles of analytical geometry. One of the earliest graphs in the physical sciences, drawn by the English polymath Edmond Halley (1656–1742) to show hypothetical air pressure as a function of altitude (Halley 1686; 1809, pl. IX fig. 7), clearly reflects this geometric legacy in the way it is presented (Fig. 1). However, by 1765, a graph of change in magnetic declination as a function of time, by the German physicist Johann Lambert (1728–1777) has very much the look of a modern graph, with coordinates marked off along the axes (Fig. 2; Lambert 1765, pl. V fig. IV).

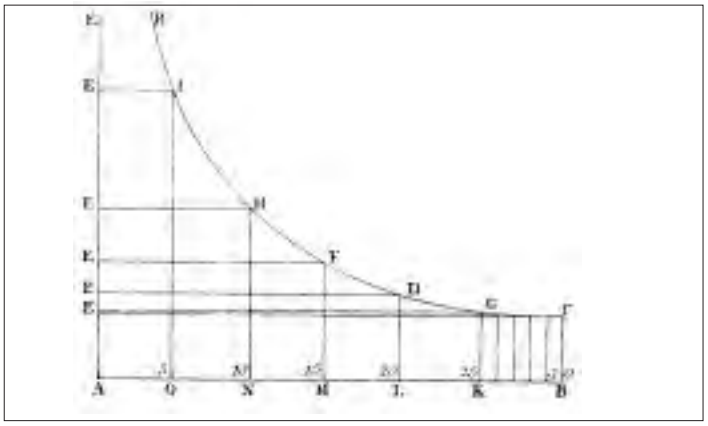

Figure 1 Edmond Halley's graph (1686; 1809, pl. IX fig. 7 — curve RIHFDGC) relating air pressure (inches of mercury; ordinate) to altitude (feet; abscissa).

It was the observational science of meteorology that increasingly led to graphical innovation. One of the earliest such graphs was described by the English naturalist and physician Martin Lister (*c.* 1638–1712), who may have been the originator of a 'Diary of the Weather': a graph of daily temperature and/or air pressure, perhaps with written observations on the wind, etc. In 1684, the members of the Philosophical Society of Oxford were shown:

> "His way of keeping the Account of the Barometer which is the most easy and exact that wee ever saw. From a plate he takes his paper, which is to be a months reckoning. It consists of oblong squares, one side of the paper is marqued the days of the month to 31, an other side the inches of the quicksilver between 28 and 31, each divided into 10 parts; there needs no more than draw a red line where the heighth is such a day, this makes in a month one red line the length of the paper bending as the quicksilver has risen or fallen, by seeing this line he says he can tell what weather has been." (quoted in Gunther 1939, 41).

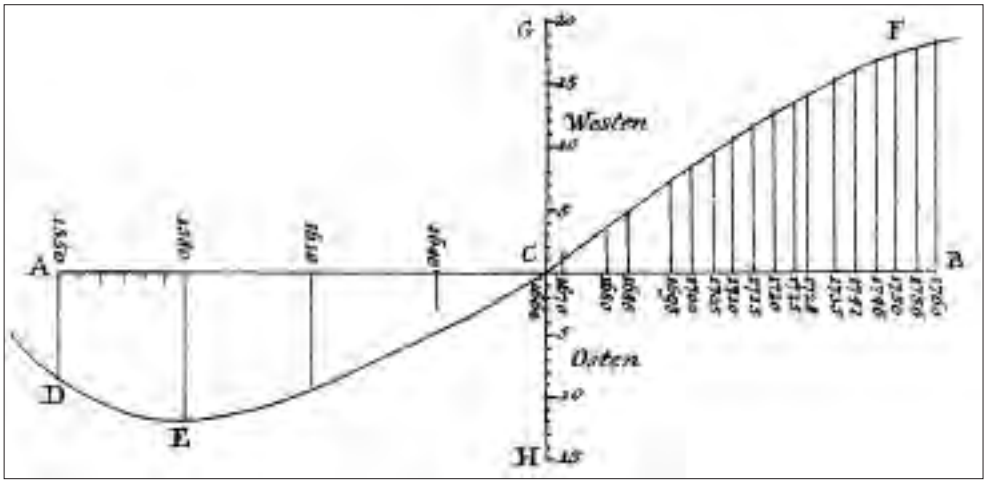

Figure 2 Johann Lambert's graph (1765, pl. V fig. IV- curve DECF) of mean annual magnetic declination (degrees) as a function of time over the years 1550–1760.

OUGS Journal 29 (2) Symposium Edition 2008, 70–80
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Lister's method was so 'mightily approved of', that printed graph paper for the purpose was soon being commercially produced and sold by the mathematical instrument maker John Warner (*fl*. 1682–1700), from his shop in Lincoln's Inn Fields, London (Gunther 1939, 139, 304). Just over 100 years later, the German astronomer and topographer Ulrich Schiegg (1752–1810), published a slightly more sophisticated graph, which compared daily temperatures at Salzburg, Innsbruck, Stuttgart and Göttingen over the winter of 1798/99. Its data points were individually delineated and different line styles were used to denote the four time series (Schiegg 1799, pl. II). In 1845, the French civil engineer Léon-Louis Chretien Lalanne (1811–1892) demonstrated the use of contoured (isoline) surfaces, which he called 'topographical tables', to show the variation of mean temperature as a function of both the hour of the day and the month of the year; his work also made use of histograms, together with wind roses and pie diagrams to depict directional (wind) frequency data.

The Scottish engineer and political-economist William Playfair (1759–1823), younger brother of the mathematician, John Playfair (1748–1819), best known to geologists as the interpreter of James Hutton's *Theory of the Earth* (Hutton 1795; J. Playfair 1802), had been introduced as a child to the art of keeping a weather diary (in the form of a 'register of the thermometer') by his brother (W. Playfair 1805, xvi f.n.). Some years later, in about 1785, the younger Playfair "thought of applying lines to the subject of finance" (W. Playfair 1798, 5), and the econometric time series was born (see Klein 1997 for a very readable account of the evolution of time series analysis from mere graphical display to a sophisticated statistical specialisation). However, W. Playfair also introduced the proportional-length bar chart (1786) and, in 1801, proportional-area circles and the pie diagram. All of these techniques came to be staple elements of the palette of graphical methods. In the earth sciences, examples of essentially econometric data displayed in this tradition include time series of mineral production, which largely appeared in literature concerned with mining (economic) geology from the 1840s onwards (early examples include: Hunt 1846; Herder and Gätzschmann 1849). The use of proportional squares and pie diagrams to illustrate mineral production data had a brief popularity around the end of the 19th century (Keppen 1894, pl. VII, VIII; Anonymous 1907, figs. 88–94).

Another person whose work influenced the growth of graphical displays was the Belgian social scientist and statistician, Adolphe Quetelet (1796–1874). He was one of the very first people to begin to think about 'statistics' (a term that initially just meant the collection of numbers about things), and he demonstrated the importance of the mean as a measure of the centrality of a frequency distribution. In 1827 and 1838, he published graphs that show curves of the annual variation by month of the numbers of births and deaths in Brussels, together with the corresponding mean monthly temperature, all plotted as a function of the months of the year. The obvious inverse relationship between these two sets of data (maximum mortality occurred in January to March; minimum in July) caused interest all over Europe, because people were so struck by the fact that one could actually illustrate the relationship between two measurable attributes in this sort of way. Quetelet also discussed the use of empirical frequency distributions.

Later, two highly influential textbooks on the graphic method were published. The first (Minard 1862) was by the French civil engineer Charles Joseph Minard (1781–1870), who devised a number of innovative cartographic displays and in particular used proportional-width lines to denote the increasing/decreasing quantity of something (the amount of wine, number of passengers, etc.) as a function of transportation distance. The second (Marey 1878) was by his countryman Étienne-Jules Marey (1830–1904), who described examples mainly taken from physiology and medicine.

Early use of graphs in the earth sciences

When the Scottish physicist David Brewster (1781–1868) deduced the law named after him in the course of studies of the polarisation of light reflected from transparent crystals (Brewster 1815) — i.e., the index of refraction is the tangent of the angle of polarization — he accomplished it solely using data presented in tabular form. Today, one would naturally begin by plotting the data graphically to see the actual form of the relationship between the two variables (it could, after all, turn out to be non-linear) but, at that time, it was simply not an obvious way to proceed, even to someone of Brewster's intellect.

Quetelet's ideas and, indeed, his graphic style, were adopted in 1843 by the French mathematician and astronomer Alexis Perrey (1807–1882) for use in his pioneering earthquake catalogues. Figure 3 shows one of Perrey's *courbes seismiques* [seismic curves] (Perrey 1844, 97 and pl. I), one of several illustrations of the monthly frequency of earthquakes occurring in various parts of Europe during 1843, together with *roses seismiques* [seismic roses] (Perrey 1844, 107 and pl. II) showing the frequency distribution of the directions from which the earthquake shocks were supposed to have propagated, based on observations of damage to buildings, etc.

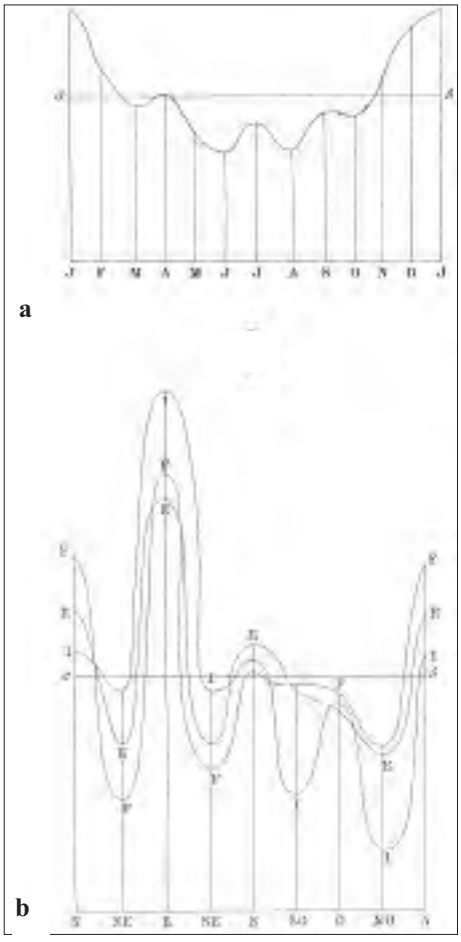

Figure 3 Examples of Alexis Perry's synopses of earthquake data: (a) Courbe sismique*: the relative frequency of earthquake shocks per month for France (line ab shows the overall mean; Perry 1845, pl. I fig. 1); (b)* Rose sismique*: comparative plot of the relative frequency of the direction from which the shocks were estimated to have come in France (F), Italy (I) and the rest of Europe (E) (line ab shows the overall mean; Perry 1845, pl. II, fig. 11).*

The methods of Marey and Minard were later reflected in maps related to economic geology, such as that made by the French Inspector General of Mines and geophysicist Charles Lallemand (1857–1938), showing the amounts of lignite coal transported by water and railway to the cities and towns of northern Germany (Lallemand 1881, pl. IX). However, the concern here is with graphs rather than thematic maps. Arthur Robinson (1982) gives an excellent, and well-illustrated, history of the latter, although his examples fall outside the geological sciences.

The British geologist James Forbes (1809–1868) was also a keen Alpinist and he became interested in the behaviour of glaciers. In 1844 and 1845, with the help of a number of assistants, he measured glacier movement at the Mer de Glace, near Chamonix, in the French Alps, over a total period of about a year. Two stations were established on the ice and, with the aid of a theodolite, he measured the downstream movement of the glacier at intervals throughout the year, together with the mean temperature over the same time period. In a similar manner to Quetelet's analysis of mortality data, Forbes deduced from a comparison of time series graphs for each property that there was a systematic relationship between the speed of glacier movement and temperature (Forbes 1846, pl. X; Fig. 4). Today, one would have displayed such data as a scatter-plot with temperature plotted along the horizontal axis (abscissa) and amount of movement on the vertical (ordinate), as it is the dependent variable, but it just did not occur to Forbes to do it in this way. It was probably not until the English statistician Karl Pearson (1857–1936), who introduced the use of so many of the statistical parameters (reviewed in Stigler 1986), devised the correlation coefficient (later named after him) in 1895 (Pearson 1896), that people began to think about using the information provided by a scatter-plot to assess the strength of a statistical relationship between two measured attributes.

Although a few early examples have already been mentioned, I will now review the types of graph that have been most commonly used in the earth sciences, broadly in the order in which they were taken up.

Stereographic projection

The oldest graphical method by far is the stereographic projection (which is generally used by crystallographers to project the positions of a set of points on the upper surface of a sphere onto a horizontal plane passing through its equator, and in structural geology to project points from the lower surface). The projection was originally devised by the Greek astronomer and mathematician Hipparchos (*fl.* 180–125 BC), inventor of both plane and spherical trigonometry; it provided the basis of the instrument known as the astrolabe (Anonymous 1976), which enabled one to find one's position on Earth from sightings of the stars. The earliest extant example is a combined stereographic net and star map in the *Libros del Saber de Astronomia [Book of Astronomical Knowledge]* compiled for King Alfonso X of Spain in 1252 (reproduced in Howarth 1996a, fig. 4), but thought to be based on an illustration in an earlier manuscript (*c.* 1070), based on the work of the Spanish-Moorish astronomer al-Zarquâlâ or Arzachel of Toledo (1029–1087).

Stereographic nets were constructed on the basis of trigonometric relationships, initially simply using a ruler and compass. The radii of the latitudes and longitudes of the net are proportional to the secant and tangent of the corresponding angles (Fig. 5, *opposite*), but special geometrical instruments, such as 'the instrument of three streight rules' (Blagrave 1585, 65) had to be devised in order to accurately draw the large radius arcs required in constructing larger nets. By the 17th century, the projection had become established as a basis for the construction of both celestial and geographical atlases, e.g. the 292mm diameter 1° net (reproduced in Howarth 1996a, fig. 5) engraved by the renowned Dutch cartographer Willem Blaeu (1571–1638) for a textbook on the astrolabe (Metius 1633) by the Dutch physician and mathematician Adrian Metius (1571–1635).

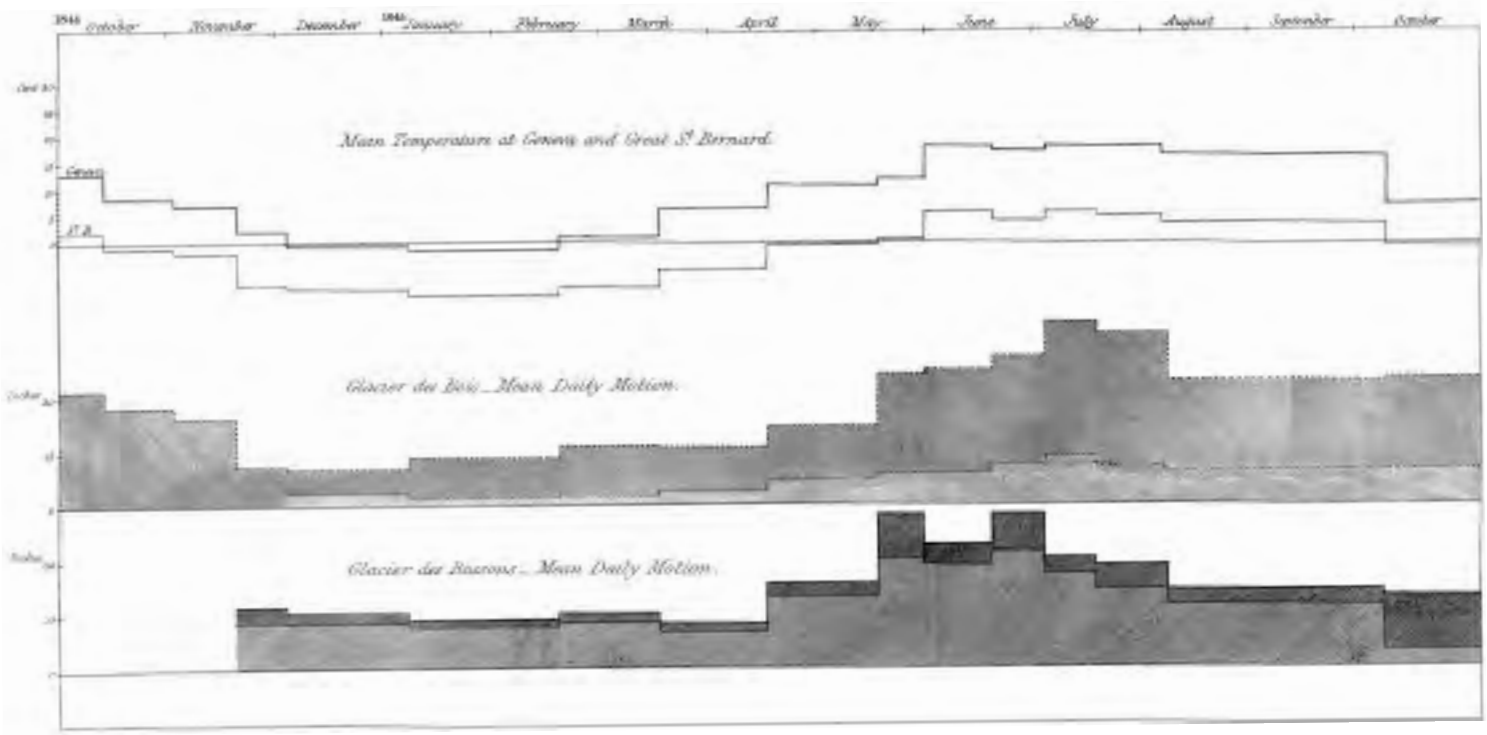
Mean Temperature at Geneva and Great St Bernard.
Glacier du Tour. Mean Daily Motion.
Glacier des Bossons. Mean Daily Motion.

Figure 4 James Forbe's (1846, pl. XI) comparison of temperatures at Geneva (upper stepped line) and St Bernard (lower) with daily movement on the Mer de Glace, near Chamionix, French Alps in 1844–5. The two sets of stepped lines in each of the hachured plots of Mean daily motion correspond to two stations on each glacier.

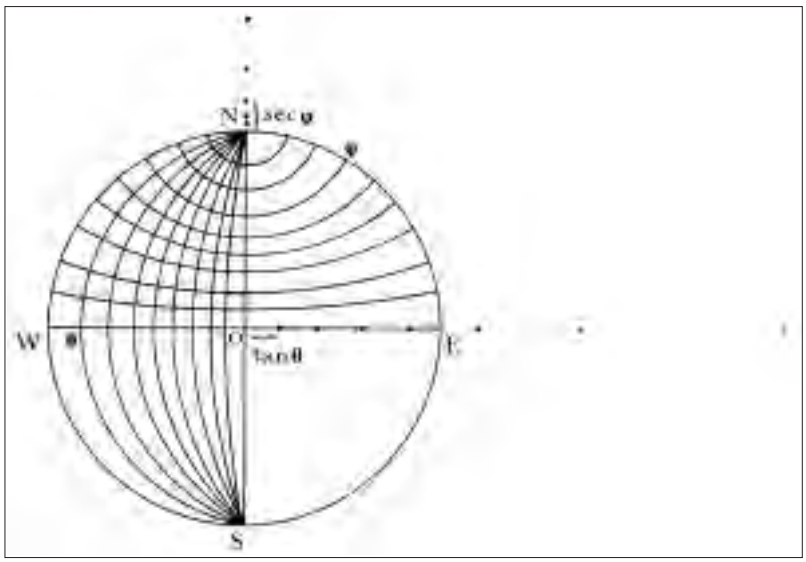

Figure 5 The constuction of an equatorial stereographic net; the centres of the first few circles for which arcs are drawn are shown by the lines of vertical and horizontal dots (Howarth 1996, fig. 3).

Once mineralogists began to measure interfacial angles in crystals, the projection became of great utility, first in mineralogy and much later in structural geology. Franz Neumann (1798–1895), Professor of Mineralogy and Physics at Königsberg [Kaliningrad] was the first to use it in his textbook on mineralogy (Neumann 1823, pl. IV, fig. 20, reproduced in Howarth 1996a, fig. 6); and its use was further popularised by the French mineralogist and petrologist, Ernest-François Mallard (1833–1894) when he published his book on geometrical and physical crystallography in 1879. Following the invention, in the 1880s, of the so-called 'universal' microscope stage — which allowed a thin-section to be inclined or rotated about any axis — the projection was widely used for the portrayal of the optical properties of minerals in thin-section, such as feldspars (Federov 1892; Michel-Lévy 1894), for diagnostic purposes. The adoption of the stereographic net as a basis on which to plot and manipulate three-dimensional orientation data in structural geology followed considerably later.

Although first devised by the Swiss mathematician and physicist Johann Heinrich Lambert (1728–1777), the *equal-area* stereographic net (Lambert 1772, reproduced in Howarth 1996a, fig. 8) did not come in to use in geology until the principle was adopted by the Austrian mineralogist Walter Schmidt (1885–1945) for plotting and analysing the spatial distribution of the orientations of the principal optical axis of quartz or calcite crystals contained, at *microscopic* scale, in the fabric of metamorphic rocks (Schmidt 1925). As a result of the pioneering work of his colleague, the Austrian geologist Bruno Sander (1884–1879) and the subsequent promotion of his methods in North America by Eleanora Frances Knopf (1883–1974) and by Harold Williams Fairbairn (1906–1994), and in England by Frank Coles Phillips (1902–1982) (Sander 1930, 1948; Knopf 1933; Fairbairn 1949; Phillips 1945), what came to be called *petrofabric analysis* subsequently gained wide usage as a means to interpret the tectonic origin of such rock fabrics. However, the controversial nature of many of the results led to its falling out of favour in the 1960s. In very recent years it has become successfully utilised through improved understanding of the origin of such fabrics and the introduction of X-ray goniometry as a tool to obtain the crystallographic orientation data (Howarth and Leake 2002). Nevertheless, use of the stereographic projection as a tool for the interpretation of *macroscopic* structural data has proved invaluable (Phillips 1954; Ramsay 1967). More detailed discussion will be found in Howarth (1996a, 1999) and in Howarth and Leake (2002).

The line chart

This is a graph in which the data points are simply joined up by lines and the original points are not shown. Perhaps the earliest example of these in the earth sciences is that drawn by John Playfair to illustrate a theoretical model relating to the behaviour of gravity over the upper surface of a cylinder (J. Playfair 1809, pl. V, fig. 27). It seems extraordinary that, when one thinks of the graphic innovation by his younger brother, the graphs in J. Playfair's own work still retained the style of geometric figures.

More commonly, early line graphs were used to illustrate such things as topographic profiles (Héron de Villefosse, 1808, pl. I; reproduced in Howarth 2002, fig. 4), and time series. The earliest examples of the latter in earth science literature were probably those drawn by Perry (mentioned above) in his many reports on earthquake occurrence for various parts of the world but, until the late 20th century, time series charts were almost exclusively confined to the depiction of econometric aspects of metallic mineral or coal production (Hunt 1846, pl. 9; reproduced in Howarth 2002, fig. 6; Herder and Gätzschmann 1849, pl. I). In fact, it was quite unusual to explicitly show the individual data points on the basis of which the line graph was drawn. An early example by the French mineralogist Julien Thoulet (*fl.* 1843–1922) shows the results of a series of sedimentation experiments, and includes both the data points as well as lines and curves fitted to them (by eye) (Thoulet 1891, pl. 1; reproduced in Howarth 2002, fig. 7); a contemporary, mineralogical, example occurs in a study of the optical properties of crystals by the Russian mineralogist Georgii Yuri Viktorovich Wulff (1863–1925) (Wulff 1890, fig. 4).

By the late 1800s, the rapidly growing study of igneous geochemistry gave rise to what came to be known as the *variation diagram*, in which the varying proportions of the major element oxides, typically, weight percentages of Al_2O_3, Fe_2O_3, TiO_2, FeO, MnO, CaO, MgO, K_2O, Na_2O and P_2O_5, were shown by multiple lines with a common ordinate, as a function of increasing SiO_2 along the abscissa. In early examples, such as that of the Austrian petrologist Eduard Reyer (1849–1914) values of SiO_2 were included in the graph, as well as being implicit in the ordering of the specimens along the abscissa (Reyer 1877, fig. I). Not many years after, the American geologist and igneous petrologist Joseph Paxton Iddings (1857–1920) promoted the use of explicit coordinate values for the molecular proportion ('variation') of silica in his graphs (Fig. 6, *overleaf*; Iddings, 1892, fig. 80). The same type of diagram, plotted in terms of weight percentages rather than by molecular proportions, was subsequently popularised by the English igneous petrologist Alfred Harker (1859–1939) as the 'variation diagram', following publication of his influential textbook, the *Natural History of Igneous Rocks* (Harker 1909, 119, fig. 26). A contemporary described the diagram as "specially designed to draw attention to the relations between the compositions of rocks belonging to the same centre or region of igneous activity … in its simplicity and fertility of suggestion it is unrivalled" (Holmes 1921, 441–2).

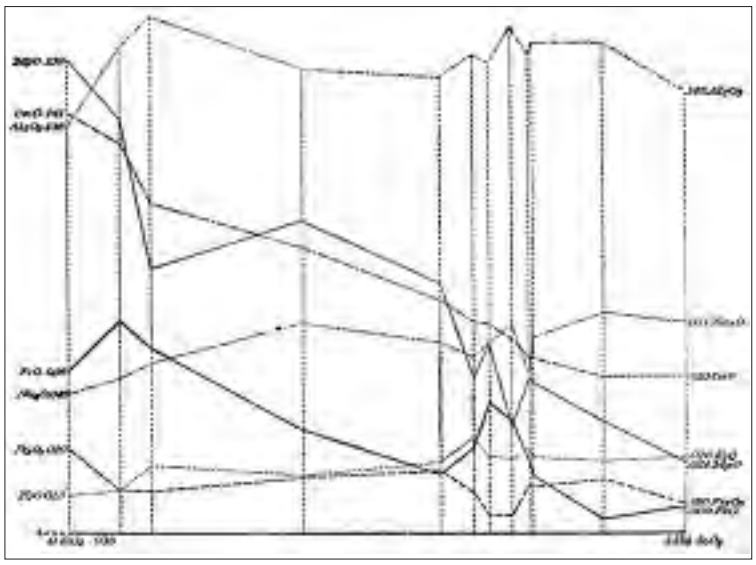

Figure 6 Joseph Idding's (1892, fig. 80) diagram of 'Molecular variation of the rocks at Electric Peak'; molecular proportions of Al_2O_3, CaO, Fe_2O_3, FeO, H_2O, K_2O, MgO and Na_2O plotted as a function of SiO_2 (abscissa).

Frequency distributions and rose diagrams

Quetelet's popularisation of the frequency distribution curve and its adoption by Perrey to illustrate his earthquake catalogues has already been mentioned. Rather surprisingly, the wider usage of frequency distributions in geology seems not to have become common until the beginning of the 20th century and, even then, it was largely confined to palaeontology and igneous geochemistry.

An early morphometric example is by the American geologist Edgar Roscoe Cumings (1847–1967) and his student [?Ada Virginia] Mauck [?b. 1877] (Cumings and Mauck 1902, fig. 1). In geochemistry, Harker (1909, 148, fig. 42) illustrated the abundance of SiO_2 in igneous rocks, but, as time went by and more data was accumulated, it became apparent that this composite distribution was in fact strongly bimodal, as was illustrated by the American petrologist Henry Hollister Robinson (1873–1925) (Robinson 1913, 202, fig. 34). He also demonstrated (Robinson 1916, fig. 1) that the frequency distribution of error in the 'total' oxide percentages of 3,391 complete chemical analyses of igneous rocks was well fitted by the normal distribution model. Subsequently, the English civil engineer and petrologist William Richardson (1887–1965) showed that, by using a statistical technique introduced by Pearson (1894), this bimodal curve could be decomposed into a mixture of two normal distributions (Richardson 1923, fig. 1) with modes at 52% SiO_2 (basalt) and 73% SiO_2 (granite).

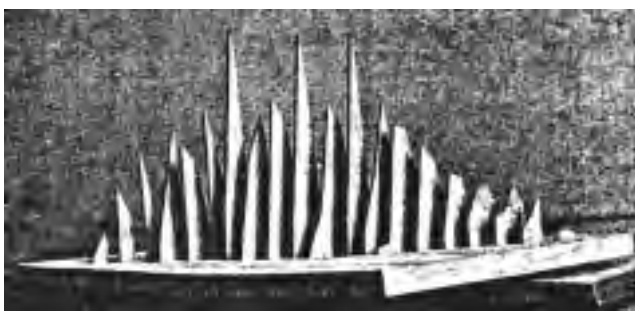

Figure 7 One of William Alkins' (1920, fig. 2) models of bivariate frequency distributions of shell length versus depth in 945 specimens of Reticularia lineata from the Carboniferous Limestone of Castleton, Derbyshire, UK.

Bivariate frequency distributions also made a rare appearance. The English chemist and malacologist William Ernest Alkins (1896–1969) published photographs of his models of bivariate frequency distributions of shell length versus width and depth (Fig. 7) for 945 specimens of the brachiopod *Reticularia lineata* from the Carboniferous Limestone of Castleton, Derbyshire (Alkins 1920, figs. 1 and 2).

Surprisingly, the portrayal of frequency distributions of spatially directional data came into general use rather earlier. Perrey's work in 1844 has already been mentioned. His adoption of the term *roses seismiques* presumably followed the introduction of *Wind-Rosen* [wind-rose] by Baron Christian Leopold von Buch (1774–1853), after the 14th-century *compass rose* (referring to the supposed resemblance between a 32-sector compass card and the petals of a rose). However, whereas von Buch simply used oriented direction lines within a compass-circle (1821, pl. VIII, figs. 12–14), it was Lalanne who showed how circular frequency plots could be used as an alternative to the conventional histogram-like representation (cf. Fig. 3b) to illustrate predominant wind directions (Lalanne 1845, pl. 1, fig. 4-ter.; pl. 2, fig. 17; pl. 4, fig. 31-bis.).

In an early geological attempt to portray geological orientation data, the French palaeontologist and prehistorian Jules de Christol (1802–1861), in a letter to his fellow countryman the structural geologist Jean-Baptiste Élie de Beaumont (1798–1874), illustrated the orientation of dykes and predominant schistosity in the Cevennes region of France by simply writing the occurrence of the attribute along the appropriate sector of a 32-sector compass rose (Christol 1835, pl. I). Shortly after this, the French geomorphologist Auguste Viquesnel (1800–1867) adopted the style of the *rose de directions* used by Élie de Beaumont and his fellow countryman, the geologist Ours Pierre Armand Petit Dufrénoy (1792–1857) (Élie de Beaumont and Dufrénoy1841, I, 466) by filling 5º sectors about each mean strike direction with a number of radial lines proportional to the number of observations falling in that direction (Viquesnel 1842, pl. XX).

Some thirty years later, the French mining engineers Auguste Michel-Lévy (1844–1911) and Jules-Emile Choulette (1844–1871) were still using essentially the same method to show the orientation of various types of veins in the Freiberg region of the Erzgebirge mining district, Czechoslovakia (Michel-Lévy and Choulette1870, pls. VII, IX, X; part of pl. VII is reproduced in Howarth 1999, fig. 7). In fact, similar depictions of the orientations of mineralised faults and fissures, using ungrouped radii, went on being used in studies of ore deposits into the 1930s (e.g. Burbank and Henderson 1932, pl. 8). The American economic geologist John Mason Boutwell (1874–1968) drew a particularly striking example (Fig. 8, *opposite*; Boutwell *et al.* 1905, pl. XXIII) distinguishing between the orientations of barren, lean and pay lodes in the Bingham mining district, Utah.

Orientation diagrams in which radius length was proportional to frequency of the number of observations within a sector also began to be used by the middle of the 19th century. The frequency of joint directions in Co. Donegal, Ireland, was so illustrated by the Irish physician and petrologist, the Rev. Samuel Haughton (1823–1837) in 1864 (reproduced in Howarth 1999, fig. 9); and the English mathematician and seismologist Charles Davison (1858–1940) drew a polygonal rose diagram (Fig. 9, *opposite*), in what is essentially the modern style, showing the directions of fall of 140 stone lamps overturned in the Japanese earthquake of

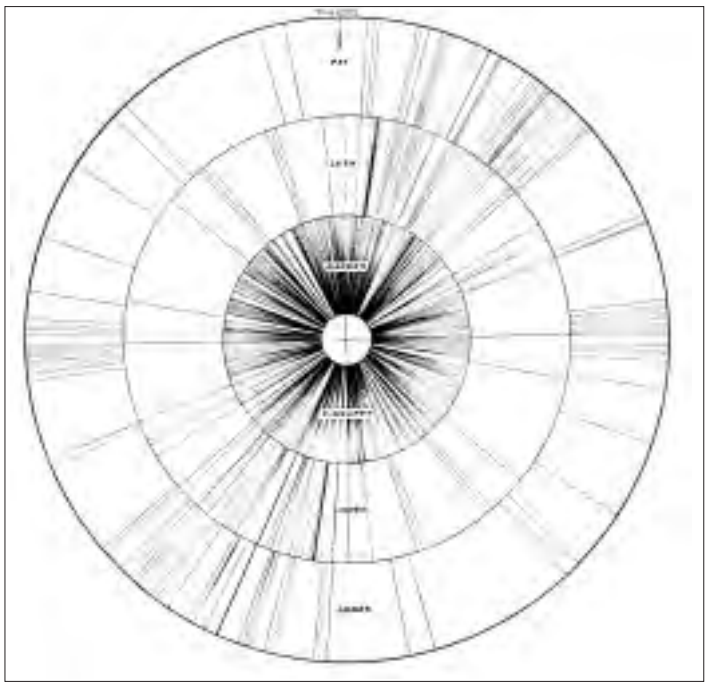

Figure 8 Trends of barren fissures (innermost circle), and of lean (central ring) and pay (outer ring) veins and lodes, in the Bingham mining district, Utah, USA (Boutwell et al. *1905, pl. XXIII).*

20 June 1894 (Davison 1905, fig. 8, 19), based on observations originally recorded by the Japanese seismologist Fusakichi Omori (1868–1923).

Scatter plots

Surprisingly, in view of their ubiquity today, the *scatter diagram*, a term introduced (Krumbein1938, 199) by the American sedimentologist and mathematical geologist William Christian Krumbein (1902–1979) for figures that simply consist of data points plotted on the basis of their Cartesian coordinates (today, also referred to as a *scatter plot*, *dot plot* or *cross plot*), was very unusual in early work. The use of such graphs essentially began with the rise of crystallography, mineralogy and igneous petrology in the 1890s (e.g. Iddings 1898, figs. 1–6; Boeke 1914, figs. 7–9). An impressive early example is by Iddings who studied the compositions of a large number of igneous and plutonic rocks selected from the 'best' analyses to have been made in the U. S. Geological Survey's laboratory up to that time. Figure 10 shows all analyses for which $Na_2O/K_2O > 2$, plotted on the basis of SiO_2 wt. % (abscissa) and $(K_2O + Na_2O)/SiO2$ wt. % (ordinate).

The use of scatter plots became more frequent following publication of textbooks such as Holmes (1921) and Krumbein and Pettijohn (1938), which included chapters devoted to the graphic method, and with a growing interest in morphometrics in

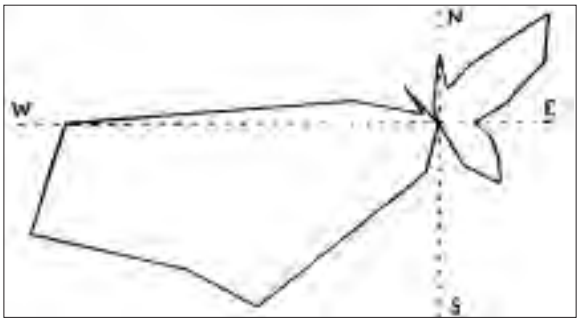

Figure 9 'Plan of directions of fall of overturned stone-lamps at Tokyo during the earthquake of 1894' (Davison 1905, fig. 8).

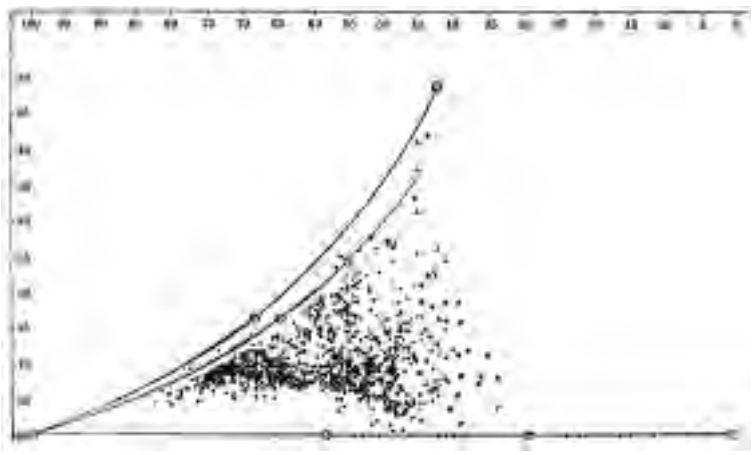

Figure 10 Compositions of 928 American igneous rocks in which $Na_2O/K_2O > 2$; plotted on the basis of SiO_2 wt. % (abscissa) and $(K_2O + Na_2O)/SiO_2$ wt. % (ordinate) (Iddings 1898, fig. 2).

palaeontology (e.g. Davies and Trueman 1927, fig. 4). The latter was prompted by the publication of the textbook *On Growth and Form* (1917) by the English biologist and mathematician D'Arcy Wentworth Thompson (1860–1948); and an article on the use of graphs in palaeontology by the English zoologist and invertebrate palaeontologist, Henry Hurd Swinnerton (1875–1967) (Swinnerton 1921).

Ternary diagram

The *ternary*, or *triangular diagram* (Bancroft 1897, 404), is one in which a point is plotted using its centered coordinate system, the coordinates mutually inclined at 60º; it represents the relative proportions (*a, b, c*) of three end-members {*A, B, C*}, generally expressed as percentages, so that $a + b + c = 100$. Its first application was probably that of the German physicist Tobias Mayer (1723–1762) in *c.* 1752, in which he illustrated colour-mixing using such a diagram, with the pigments red lead, yellow ochre and Berlin blue as end-members. It was originally drawn in black-and-white (reproduced in Howarth 1996b, fig. 1) but showed the proportions one should mix together to get particular types of colour (Georg Lichtenberg, the editor of Mayer's posthumously-collected works, succeeded in making a 7-step colour triangle based on his scheme; Mayer 1775, pl. III). However, the mathematical properties of such a barycentric coordinate system (i.e. one in which the coordinates are defined by reference to the vertices of a simplex), its geometry and a calculus based upon it, were first described (although solely in the contest of analytical geometry) by the German mathematician and astronomer August Möbius (1790–1868) in 1827. Although subsequently adopted by physicists engaged in studies of colour and photoelasticity, it was only after the formulation of the phase rule by the American physicist and engineer Josiah Willard Gibbs (1839–1903) in 1875, that the English physicist Sir George Gabriel Stokes (1819–1903) drew the first *ternary diagram* to show how the concept could be usefully applied to the study of three-component alloys (Stokes 1891, fig. 1; reproduced in Howarth 1996b, fig. 6).

Curiously, the first such diagram to appear in the geochemical literature, drawn by the Czechoslovakian mineralogist, crystallographer and petrologist Friedrich Becke (1855–1931) in 1896 (Becke 1896, reproduced in Howarth 1998, fig. 2) was constructed on a different basis: having been inspired by the {*h, k, l*} crystallographic indices for the hexagonal system, introduced by the English mineralogist and crystallographer William Hallowes

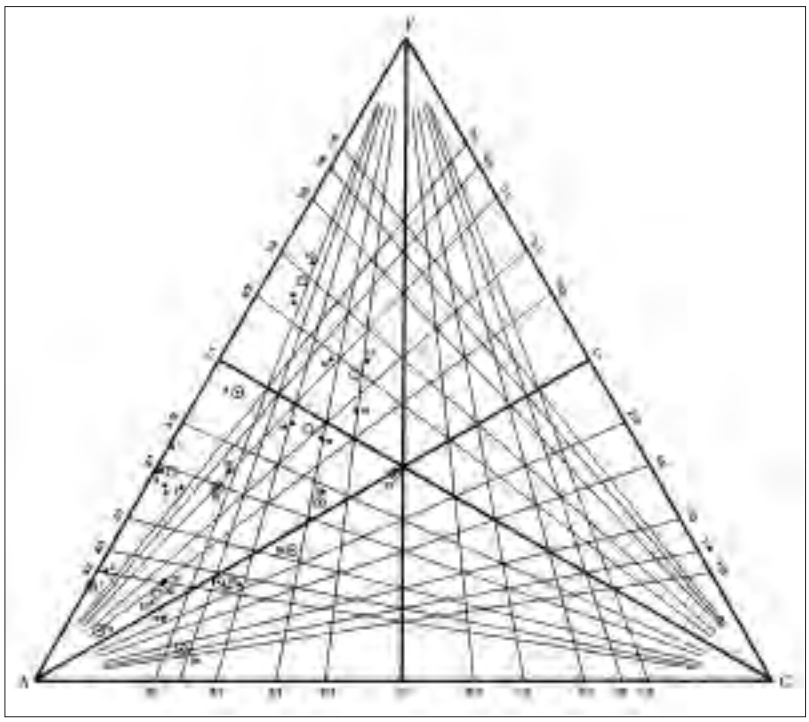

Figure 11 Examples of the granite family plotted in Alfred Osann's 'ACF' scheme for the classification of igneous rocks (see text for explanation; redrawn from Osann (1900, pl. IV fig. 2)). In the original the ratio lines are in red, the whole over a very faint blue grid.

Miller (1801–1880) in 1839. Becke used *two* coordinates inclined at 120º, with their origin at the centre of the triangle.

By the turn of the century, there was great interest in both the chemical composition and classification of igneous rocks, and a lot of experimental petrology was also being undertaken in order to understand the behaviour of silicate systems. It became considerably easier to plot such data following the introduction of 'triangular' graph paper by the American physical chemist Wilder Dwight Bancroft (1867–1953), ruled with a 60º net consisting of 1% and bolder 10% gridlines (Bancroft 1897, fig. 1; reproduced in Howarth 1996b, fig. 7). Even so, its commercial availability must have proceeded surprisingly slowly, as in 1922 the petrologist Albert Johannsen (1871–1962) published a method to facilitate the hand-drawn graphical construction of a plot of data points within a quartz-orthoclase-plagioclase triangle.

The German geochemist Alfred Osann (1859–1923) used the ternary diagram in 1900 as the basis for one of the first chemical classification schemes for igneous rocks, based on the conversion of the weight percentages of the various major oxides to molecular proportions (by dividing them by the molecular weights of the oxides). He then plotted these on a triangular 'ACF' diagram (Fig. 11): A, the sum of the molecular proportions of the alkalis; C, the sum of the molecular proportions of CaO plus MgO and FeO equivalent to any Al_2O_3 left over after its allotment to the alkalis and lime; and F, the sum of the molecular proportions of FeO and MgO plus any excess CaO. The percentages of the quantities A, C and F were then calculated in order to plot them on the diagram (Osann 1900, pls. IV–VII). Results obtained using his classification scheme were published in a series of papers between 1900 and 1903. Similar classification schemes have continued to be used in igneous and metamorphic petrology (see examples in Rollinson 1993).

The increasing interest in igneous petrology and geochemistry, and the publication of many textbooks on petrographic methods, led to the publication of numerous ternary diagrams from the early 1920s onwards, particularly in the field of igneous petrology. By the late 1940s, their use had also spread to sedimentary petrology and sedimentology. The American sedimentologist and marine geologist Francis Parker Shepard (1897–1985) reviewed in 1954 various classification schemes, based on sand-silt-clay ratios, which had recently been proposed. Krumbein (1952, 1955) established quantitative sedimentary *facies mapping*, in which ternary classification schemes based on lithological attributes (such as the sandstone-shale-limestone or sandstone-shale-non-clastics thickness ratios) in stratigraphic sections, or wells, passing through a particular formation could be usefully overlaid on isopach maps of the formation thickness. The use of this approach was popularised following publication, with his colleague Laurence Louis Sloss (1913–1996), of their textbook *Stratigraphy and Sedimentation* (Krumbein and Sloss 1959, ch. 6). See Howarth (1996b) and Sabine and Howarth (1998) for further discussion.

Multivariate frequency polygons

It is easy to forget that, until the recent years of computer graphics, all statistical illustrations were drawn by hand; and that a standard chemical analysis of a rock was, until the advent of X-ray fluoresence analysis in the 1960s, still being performed by the classic methods of wet chemistry (e.g. Washington 1919). Typically, most or all of the major oxides (SiO_2, Al_2O_3, Fe_2O_3, TiO_2, FeO, MnO, CaO, MgO, K_2O, Na_2O, P_2O_5 wt. pct.) would be reported and, for some applications, these would be recalculated as normative values etc. under one of a number of possible schemes. It was realised that, in order to best compare compositions of different individual rocks (as opposed to the overall trends shown by a variation diagram), a graphical display embracing the essential features of the *entire* composition of each might be helpful. Perhaps inspired by the use of multiple curves, or divided bars, to represent the proportions of the oxides in each rock type plotted in variation diagrams (see above), this encouraged graphic innovation in the form of multivariate symbols. Figure 12 (*opposite*) shows six of these by the French mineralogists Michel-Lévy in France and Otto Mügge (1858–1932) in Germany; and by petrologists Waldemar Christopher Brøgger (1851–1940) in Norway, Franz Loewinson-Lessing (1861–1939) in Russia, and Iddings in America (Michel-Lévy 1897a, 1897b; Brøgger 1898; Loewinson-Lessing 1899; Mügge 1900; Iddings 1903).

The most interesting graphical display produced using multivariate symbols is that by Iddings, which he developed as an extension of his 1898 work, mentioned above. He adapted his symbol from that of Brøgger (1898) and plotted the centre of each in the diagram using SiO_2 and $(K_2O + Na_2O)/SiO_2$ wt % coordinates, as before. For additional clarity, he coloured the four triangular sub-regions of each symbol: lower right (MgO, CaO) blue; upper right (NaO, Al_2O_3), yellow; upper left (Al_2O_3, K_2O), green; and lower left ($2Fe_2O_3$+FeO, CaO) red. If TiO_2 were present in 'appreciable' amount it was plotted to the left of the zero point, parallel to the abscissa. He concluded that the overall figure (Iddings 1903, pl. I), which consisted of several hundred individually coloured symbols for igneous rocks containing more than 27% SiO_2, convincingly demonstrated:

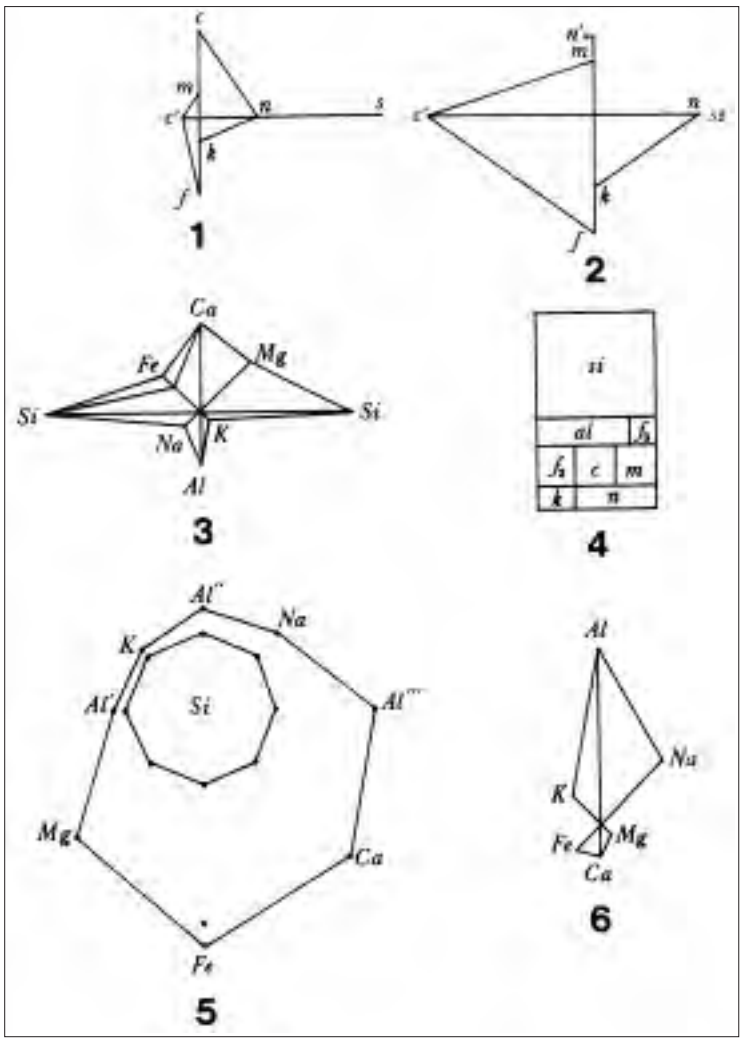

Figure 12 Examples of types of multivariate graphics used to represent the chemical composition of an igneous rock: 1, Michel-Lévy 1897a, pl. VII; 2, Michel-Lévy 1897b, fig 2 and pls X–XV; 3, Brøgger 1898, pl. I; 4, Loewinson-Lessing 1899, pl. IV; 5, Mügge 1900, pls V–VI; and 6, Iddings 1903, pl. I (Howarth 1998, fig. 5).

"that there are gradual transitions in the chemical composition of igneous rocks from one extreme to another, that there are no recognizable groupings of rocks or noticeable subdivisions of the chemical series, and that chemically similar rocks occur in genetically different families, it follows that the subdivision of all igneous rocks into groupings for purposes of classification must be along arbitrarily chosen lines. And the intricate character of the chemical variations, apparent in the diagrams, prevents a simple quantitative statement of any possible limits which may be selected for subdivisions of the series, however arbitrarily chosen." (Iddings 1903, 69)

Unfortunately, probably because they were so tedious to draw by hand, the use of multivariate symbols fell out of use around 1910 and was not taken up again until their construction was facilitated by the arrival of computer graphics in the late 1960s.

Nevertheless, igneous petrology was one of the areas where the use of graphs was most rapidly taken up (Fig. 13). A few other types of graph were also occasionally used in other fields, e.g. polar diagrams in studies of crystal optics, such as those by the French physicist Jean Baptiste Biot (1774–1862) using Iceland spar (e.g. Biot 1817, pl. IV, fig. 14); and divided-bar charts were

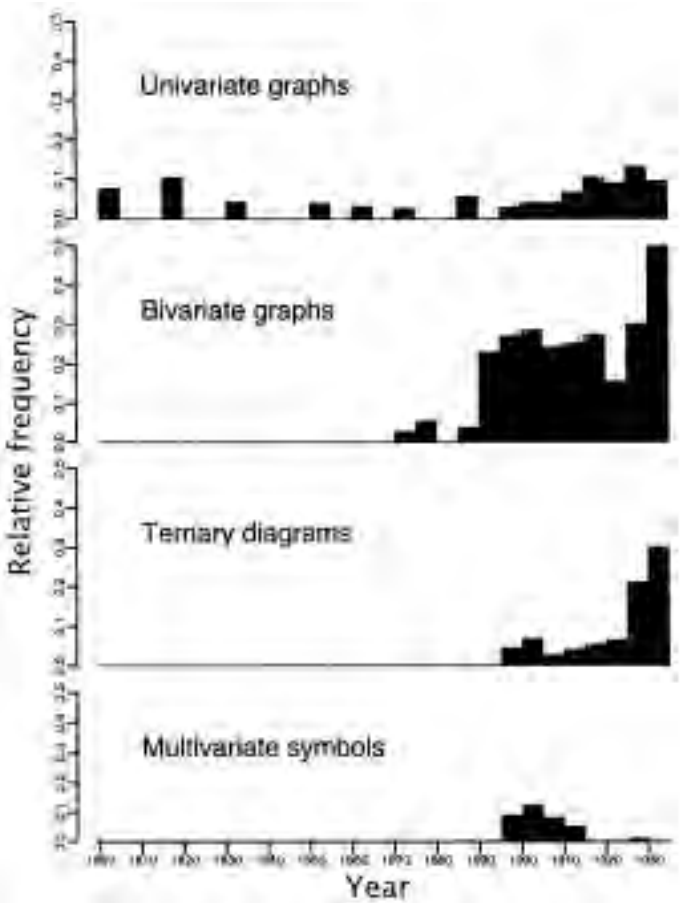

Figure 13 Usage of different types of graph in igneous petrology, 1800–1935 (adapted from Howarth 1998, fig. 1).

occasionally used to compare rock compositions (Brammall and Harwood 1925, fig. 1).

The computer age

As time went by, the time lag before earth scientists adopted a graphical technique that had originally been developed outside their field gradually became shorter and shorter, and a major decrease followed the introduction of computers into universities after the Second World War, first in America and later in Europe (Fig. 14, *overleaf*) as the computer enabled graphs of all kinds to be far more easily produced than drawing them by hand. The situation was further eased with the gradual introduction of software packages.

While these developments led to much innovation in statistical methods, including methods for graphical data display, only a small number of the new, purely graphical, innovations have been taken up in the earth sciences. These include:

1. The *boxplot* (which can be thought of as a 'top-down' view of a histogram) for univariate comparison of the distribution of the same variable across a number of classes, introduced by the American statistician John Wilder Tukey (1915–2000) in 1977 and now a standard component of most statistical software packages.
2. *Kleiner-Hartigan trees*, a method introduced by the American statisticians Beat Kleiner and John Hartigan (1981) to aid comparison of multivariate abundance (the problem discussed in the previous section). The data for each sample to be compared was plotted using the same tree-like topology of the graphic symbol (based on a prior hierarchical cluster analysis of the correlation

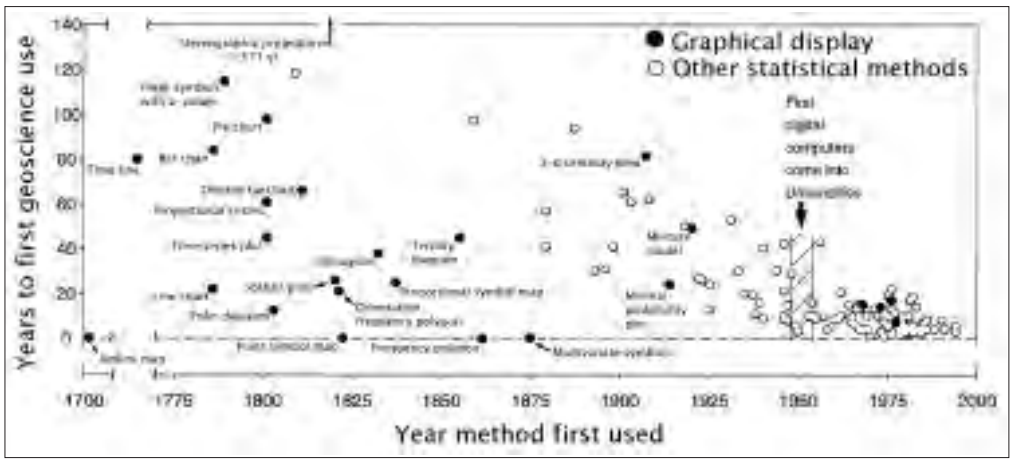

Figure 14 Time lag before a statistical graphic method was taken up and used in the earth sciences, based on first-appearances of a given technique in the earth science literature and outside the field (modified from Howarth 2002, fig. 11).

matrix for all the variables used) with branch-lengths in each tree proportional to relative abundance. Early geological examples of the application of both these methods are given by Howarth (1984, figs. 2 and 3). Regrettably, the extremely effective Kleiner-Hartigan trees eventually fell out of use in the late 1980s as a result of insufficient portability of the software.

3. The *radial* or *Galbraith plot*, for the comparison of a number of point-estimates of differing precision, introduced by the British statistician Rex Galbraith, and now widely adopted for the display of comparison of fission track age estimates (Galbraith 1988, 1990, 2005).

Readers interested in finding out more about the early history of graphical methods should investigate: Shields (1937), Funkhouser (1938), Royston (1956), Tilling (1975), Beniger and Robyn (1978), Fienberg (1979), Tufte (1983), Hankins (1999) and Spence (2005); and geological applications have been discussed by Howarth (1984, 1996a, 1996b, 1998, 1999, 2002).

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An introduction to the history of geological conservation in the United Kingdom

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Abstract

Early attempts to conserve earth sciences sites are summarised and followed through to the establishment of the Conservation Agencies, the Geological Conservation Review (GCR) and the effects of the Countryside and Rights of Way Act. The legal basis for geological conservation is outlined, taking into account the different legislation and conservation mechanisms throughout the UK. The basis for the choice of the best geological sites in Great Britain as Sites of Special Scientific Interest (SSSIs) through the Geological Conservation Review and the comparable exercise in selecting Areas of Special Scientific Interest (ASSIs) in Northern Ireland are explained. The rationale for listing other important, but non-statutory, sites listed through the Regionally Important Geological Sites (RIGS) scheme is outlined. The international initiatives World Heritage Sites, Geoparks and Global Geosites are shown to impinge on geological conservation in the UK. The technicalities of the registration of SSSIs and ASSIs are then outlined showing how they provide a mechanism for consultation about potential damages to the special interest of the sites.

Introduction

There has been interest in geology for well over 200 years, stimulated by industrialisation in the early 19th century and the need for quarrying, mining and the construction of canals and railroads to be done on a more structured and scientific basis. Books were published on many geological topics and the first geological maps were printed in the early 19th century. The British Geological Survey was established in 1835 and many universities and colleges started geology courses.

Collecting fossils and minerals became popular among both professional 'geologists' and amateurs, but geology first caught the general public's attention with the establishment of the world's first 'geological theme park' in the grounds of the Crystal Palace when the building was moved from Hyde Park to South London following the Great Exhibition in 1851. Full-scale dinosaurs were reconstructed on rocks of the same age within which their fossils had been found. Selective plantings were added to simulate the vegetation that was growing when these animals were alive. There were also reconstructions of geological sections, a coal mine and a lead mine (Fig. 1) (see Doyle 2008 for more details).

Many exciting discoveries of fossils were made during the 19th century, but nearly all ended up in private collections or in the new museums that were being built around the country. A very few sites were thought of as 'natural monuments' and attempts were made to prevent then becoming spoiled through commercial exploitation. Around Edinburgh there are several that have survived for a number of reasons: There are the Dinantian volcanic rocks within Edinburgh itself, including Castle rock, Carlton Rock, and Salisbury Crags and Arthur's Seat in Holyrood Park; a cluster described as "one

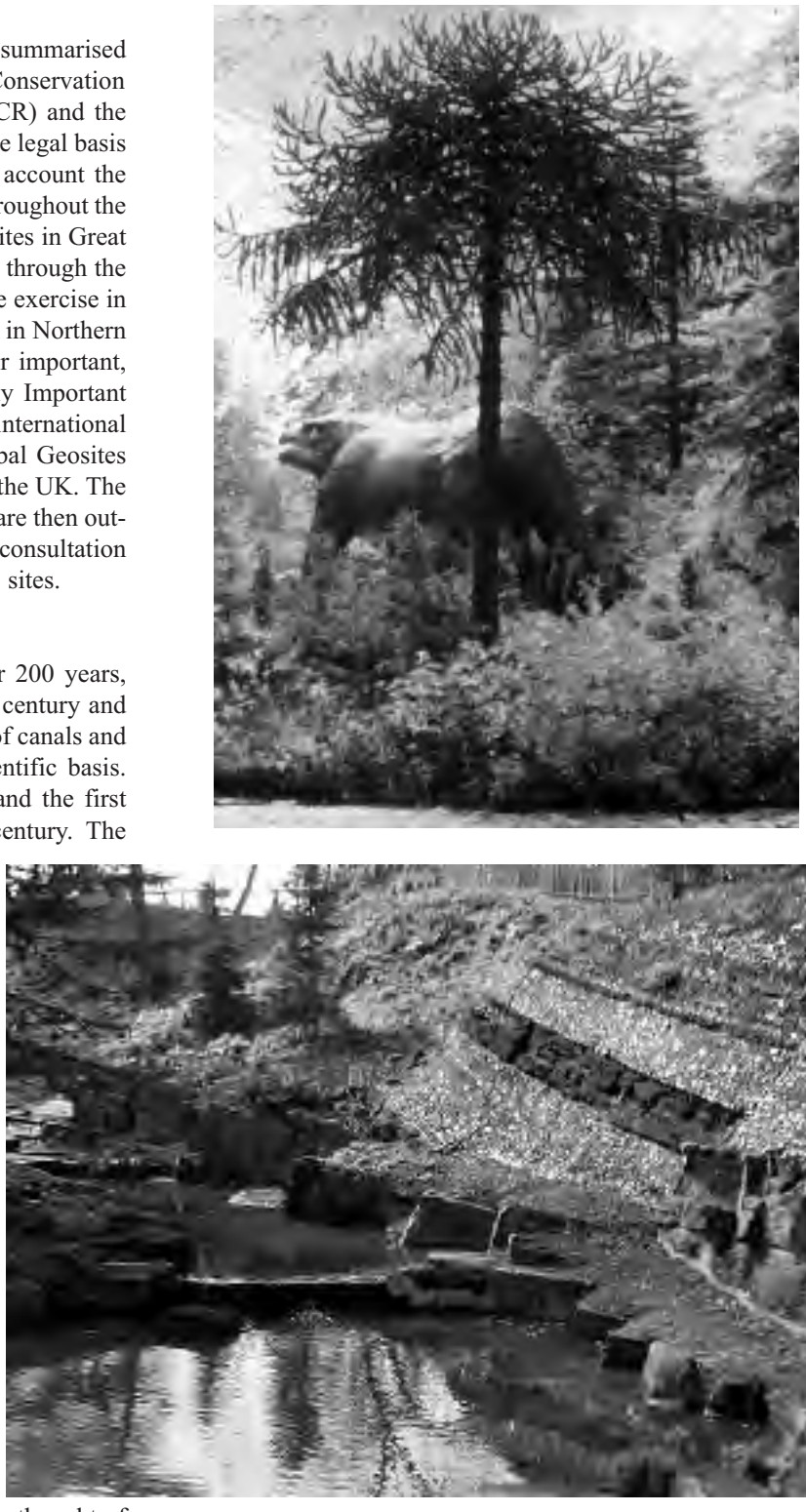

Figure 1 Victorian geological models at the 'Crystal Palace Dinosaur Park': top, The Wealden part of the Secondary (Mesozoic) Island as it was constructed in the early 1850s with a reconstruction of Iguanodon next to Araucaria araucana, the Monkey-Puzzle Tree, as part of the 'contemporary' planting; bottom, the restored strata of the 'Coal Formation' complete with coal seam and two faults.

OUGS Journal 29 (2) Symposium Edition 2008, 81–7
© OUGS ISSN 0143-9472

Figure 2 Hutton's Rock with the quarried face of Salisbury Crag in the background.

of the prime geological sites in Scotland if not in the whole of Great Britain" (Upton 2003). Hutton's Rock on Salisbury Crag is a vein of iron ore (haematite) and is of considerable interest because the geologist William Hutton managed to save this unusual and interesting geological feature from quarrying. It probably represents the earliest known example of geological conservation in the world (Fig. 2). And there is Agassiz Rock, where in 1840 Louis Agassiz saw evidence of ice action in smoothing, striating and undercutting and deduced that ice sheets once covered the area.

Two other early conservation efforts involved the large basal portions of what we now know to be arborescent lycophytes. Such fossils, called *Stigmaria*, had been seen before in quarrying and mining but in 1874 a group of them was found during excavations for the Wadsley Lunatic Asylum near Sheffield. The Professor of Geology at Sheffield believed them to be important enough to preserve some of them. Three were enclosed in specially constructed buildings (Fig. 3) (Sorby 1875). Unfortunately the buildings deteriorated with time and collapsed in the late 20th century. Excavations during the redevelopment of the site for residential purposes revealed remains of many more stigmarian bases and fallen stems (Boon 2004). In 1887 another group was uncovered during excavations for the new Victoria Park in Glasgow. The City Council was persuaded that they should be saved and authorised the construction of the glass-roofed building that still protects this world-famous 'Fossil Grove' (Fig. 4) (Cleal and Thomas 1995; Gunning 1995).

Figure 3 (right) One of the original buildings at Wadsley containing Stigmaria.

Figure 4 (left) The 'fossil forest' inside the building at Victoria Park, Glasgow.

The more recent general appreciation that many geological sites are worth protecting has led to government legislation that is described below. Some of these sites have a large degree of self-preservation built into them. For example, the world famous Devonian Chert at Rhynie in Scotland with its petrified plants and animals has been studied by many renowned palaeontologists since it was discovered in 1913 (Cleal and Thomas 1995; Thomas and Cleal 2000). It survived exploitation only because there was no natural outcrop and the only way of obtaining new material was to dig a trench (Fig. 5). In contrast, Hugh Miller's

Figure 5 The author in the trench cut into the Rhynie Chert for the Tenth International Congress Edinburgh in 1964.

Devonian fish locality exposed on the beach at Cromarty was virtually destroyed within 20 years by over-collecting. Other sites survive because they were simple too large to be destroyed, such as the Whin Sill, Fingal's Cave and Chesil Beach. Caves are also safe up to a point, although many have lost their stalactites and stalagmites, which have been taken as souvenirs or for sale, or even just smashed by vandals. A major problem for conservation here is that a cave belongs, *de facto*, to the owner of the overlying land, so large cave systems might have several owners even if there is only one entrance. In practice, property rights in the caves may be sold off, giving the owner of the entrance full rights to the whole system (Ford 1990).

The legal basis for geological conservation

In Britain, in feudal law, all land under Norman control was owned by the monarch. Large parcels of land were granted to his loyal followers, a system that created private ownership and resulted in large estates being past down the generations under a complicated system of inheritance law. Ownership brought with it almost complete power and control of the land — a system that was accentuated by the numerous Enclosure Acts of the 18th and 19th centuries (Thomas 1999). In such a class-ridden society, where politicians were drawn from, and elected by, a land-owning minority, there was no will in Parliament for the establishment of National Parks, reserves or national monuments, as other countries were doing at the time (Thomas 2005).

Surprisingly, our legislative history of site designation has its roots in the aesthetics rather than the science of nature. The National Trust for Places of Historic Interest and Natural Beauty was founded in 1895, purpose being "to promote the permanent preservation, for the benefit of the Nation, of lands … of beauty and historic interest; and … to preserve (so far as practicable) their natural aspect, features, and animal and plant life." An Act of Parliament in 1907 gave the National Trust powers to declare inalienable those of its properties deemed to be held 'for the benefit of the nation.'

The general attitude to conservation did not fundamentally change until after the Second World War, when the new concept of nature conservation through planning legislation was developed. Nature conservation in the UK is now founded on domestic and international legislation and on international treaties and conventions to which the UK is a signatory. However, there is no overall legislation, nor single set of regulations for geological conservation that covers the whole of the United Kingdom.

The first official recognition of the need for geological conservation was in 1942 when the Chairman of the Committee on Land Utilisation in Rural Areas, the Rt Hon. Lord Justice Scott, stated that Nature Reserves included Geological Parks. In 1943 the Nature Reserves Investigation Committee suggested that Geological Monuments for geological features and sections needing control or protection should be scheduled for preservation in the same way as monuments of historical or archaeological importance. The Geological Reserves Sub-Committee was established by the Nature Reserves Investigation Committee in 1944 to advise them on 'Geological Parks' and 'Geological Monuments' and to draw up a list of such reserves for England and Wales. Geologists from the Geological Society of London, the Geologists' Association and the Prehistoric Society were invited to make suggestions that were incorporated by the Sub-Committee into their revised classification of Geological Reserves (Chubb 1945). Four categories of sites were defined as:

(a) Conservation Areas (Geological): large-scale physiographic features and areas containing many items of geological interest. Working quarries in such areas are to be registered (see under (d) below); new quarries or other works to be undertaken only after approval has been obtained from an appropriate authority advised by a scientific panel.
(b) Geological Monuments: small-scale geological features and sections of outstanding interest, to be permanently protected and kept in a good state of preservation.
(c) Controlled Sections: natural sections and artificial sections in a state of disuse, to be subject to control on account of their scientific value, in order to prevent them being irretrievably obscured by building or dumping of refuse, or otherwise rendered inaccessible.
(d) Registered sections: sections of exceptional geological importance at present used or worked, to be listed and to be kept under observation by an appointed authority, the owners or lessees being required to give notice to it of their intention to cease operations, in which event the sections in question would be considered for transference to the previous category (c).

The Sub-Committee distinguished between Controlled and Registered Sections because they felt that "restrictions on active industrial undertakings on geological as distinct from amenity grounds would do more harm than good to a science such as geology, which benefits from the goodwill of the quarrying and kindred industries."

Their 1945 list of recommended sites contained proposals for 71 Conservation Areas (two of which were proposed for the Isle of Man), 48 Geological Monuments, 198 Controlled Sections and 73 Registered Sections, and all were regarded to be of National or International Importance. It was stated that a secondary list was being prepared of sites and sections of less general interest, which might be preserved for educational use or research by local action.

Site selection was rather limited because a decision had been made to not include a representative locality for every rock type or geological formation, because it was thought that too long a list would be unwieldy for practical use. The process was also started during the war when fieldwork was largely out of the question and many geologists were in the armed forces. Many of these recommended sites were, in time, designated by later legislation, although not in the categories listed in the Sub-Committee's classification.

The post-war Labour Government took up the proposals of the Committee on Land Utilisation in Rural Areas and passed The National Parks and Access to the Countryside Act (1949). This resulted in a new organisation being set up, the Nature Conservancy (later to become the Nature Conservancy Council (NCC)), to administer the conservation side of the legislation. Although essentially intended for wildlife conservation, this legislation also specifically covered geology and geomorphology. Much later, in 1977, the NCC established the Geological Conservation Review's (GCR) to assess earth sciences sites throughout England, Scotland and Wales (Black 1985; Wimbledon *et al.* 1995). The GCR was designed to identify sites of national and international importance to include all the key scientific features of Britain's (not the UK's) earth heritage.

The selection process started later in Northern Ireland through the Earth Sciences Conservation Review, and was conducted independently from the rest of the UK.

Site selection was done between 1977 and 1991, using a rigorous set of site selection criteria. It was essential that each site should be based on a system of comparing like with like, because it is impossible to assess objectively the relative merits of, for example, a Palaeozoic stratigraphy site and a Tertiary igneous one. Therefore, the selection was based around 100 'Blocks' that divided the geology and geomorphology of the country into meaningful units of time, geography and type of rock formation. The sites were assessed on several criteria:

1. Was the site conservable?
2. Was the site's interest shown better at another British site?
3. Did the site show one feature or an assemblage of related features?
4. Did the site have an extended and complete record of the feature that it was showing?
5. Was the site representative for the feature that it was supposed to be showing, or did it give an atypical and therefore misleading impression of the feature?
6. Had the site been extensively studied?
7. Did the site have potential for future study? Palaeontological or mineralogical sites that had been 'worked out' were not normally considered.
8. Did the site yield superlative results?
9. Was the site in a significant palaeogeographical position, which, for instance, yielded data linking 'core areas' or demonstrated facies changes?
10. What was the contribution of the site to our overall understanding of the sites in the Selection Block?

After consultation with relevant specialists, a list of 3,081 GCR Sites was produced for Great Britain representing the best sites, or in some cases the only site, for the key geological and geomorphological feature. These formed the basis for a new set of Earth Sciences Sites of Special Scientific Interest (SSSIs) that underpin present-day geological conservation in Britain (Allen *et al.* 1979). The rigorous selection process meant that a site could not be designated as an (SSSI) merely because it contained several interests if none of those interests was on its own of national importance. Many SSSIs consist of a matrix of GCR Sites because a particular locality might be of national importance for several reasons or because sites lie geographically adjacent to one another. The sites have been written up in a series of Geological Conservation Review volumes (Ellis 2008).

The approach in Northern Ireland was broadly the same as that in Britain, although the rationale for site selection hinges upon:

1. a statutory obligation to designate geological and geomorphological Areas of Special Scientific Interest (ASSIs);
2. defining geological sites by placing boundaries around the features of interest;
3. and the recognition that developments are a threat that can destroy features of geological importance.

The site selection criteria are applied to determine sites of 'national significance' for Northern Ireland as an entity and they can be protected as ASSIs as discrete sites or as parts of larger earth sciences or biological sites.

Management of sites

In 1991 the NCC was broken up in to three 'national' agencies: English Nature, Scottish Natural Heritage and the Countryside Council for Wales. In Wales and Scotland, mergers with Countryside Agencies gave the new agencies powers over the National Parks and Areas of Outstanding Natural Beauty (AONBs). In England, an independent body, The Countryside Agency, retained these powers until the recent merger to form Natural England. All the Agencies have appointed independent governing bodies (Councils in England and Wales and a Board in Scotland), which determine the objectives, strategies and policies of the agency staff and decide on the notification of SSSIs. The three agencies co-ordinate their work through the Joint Nature Conservation Committee (JNCC), whose own governing body comprises representatives from the three agencies and independently appointed members. JNCC's most significant impact in geology has been their involvement in publishing the GCR volumes.

The National Parks and Access to the Countryside Act 1949, together with the Wildlife and Countryside Act 1981, enable the three statutory bodies and local authorities to establish and manage national and local nature reserves for the conservation of Earth heritage features, to purchase or lease land, or reach contractual agreements with the owners and tenants of land for protection and proper management. Compulsory purchase can be made as a last resort. There are relatively few reserves solely of geological importance in Great Britain, but there are a great many SSSIs that have geological as well as biological interest. Some of the very best sites, such as Cwm Idwal (Fig. 6) were purchased to become Nature Reserves. The agencies have a duty to notify the owners, the relevant government minister, the relevant planning authorities and any relevant public bodies of SSSI designations. This situation supersedes that which existed before the 1981 Act, when it was not a requirement for the landowner or occupier to be told that part of his property was an SSSI. Both SSSI and ASSI status provide a mechanism for consultation about threats or activities that may endanger the special interest of a site. The Agencies must inform owners and occupiers about the SSSI's location, its features of special interest, and how the land should be managed to maintain that interest. To that end, a list of Operations Likely to Damage (OLDs) or Potentially Damaging Operations (PDOs) is produced to protect the site's scientific value. Those placed on geological SSSIs are generally concerned with modification of the rock exposure, mineral extraction, dumping, storage against the exposure, the erection of

Figure 6 Cwm Idwal in North Wales is a SSSI, a GCR site and was the first Nature Reserve to be designated in 1954. It is a classic example of a landscape sculptured by ice. Rare arctic-alpine plants also grow on the cliffs. In a 2005 Radio Times poll Cwm Idwal came seventh in the list of greatest natural wonder in Britain.

permanent or temporary structures, tree planting, recreational activities such as rock climbing or motorbike scrambling, and coastal defences. The Countryside and Rights of Way Act 2000 strengthened the legislation for both geological and wildlife conservation in England and Wales by putting the emphasis on supporting owners and occupiers of SSSIs to manage their land positively to benefit conservation aims. The Act also makes it an offence for anyone to damage an SSSI whether knowingly or recklessly. The Countryside Council for Wales and English Nature can also introduce byelaws on SSSIs to protect against third party damage and deal with vandalism and other damaging activities through the courts (see Thomas and Cleal 2005, and Thomas and Warren 2008 for further details and references therein).

In Northern Ireland, the Nature Conservation and Amenity Lands (Northern Ireland) Order 1985, as amended by the Nature Conservation and Amenity Lands (Amendment) (Northern Ireland) Order 1989 affords a comparable degree of protection to its ASSIs and their notification has been undertaken by the Northern Ireland Environment Agency since July 2008. For more information on the history of geoconservation in the Republic of Ireland see Parkes (2008).

Local authorities are able to protect SSSIs from adverse development under the controls provided by the Town and Country Planning Acts, although designation cannot overrule existing planning permission. Planning Policy Guidance is provided on nature conservation relating to England and there is also a requirement to consult the relevant agency when a planning application affects an SSSI. It is an offence to intentionally or recklessly destroy or damage any geological or physiographical features by reason of which the land is of special interest. In Scotland there is only guidance on the implementation of the EC Habitats and Birds Directive. In Wales there are circulars on Nature Conservation and Planning Controls over Sites of Special Scientific Interest.

Some SSSIs are safe from damage or neglect in being owned by local authorities or NGOs, such as local conservation trusts, the National Trust, and the British Institute for Geological Conservation (Fig. 7), all of which have remits to protect them. A few are in private hands and open to the public as tourist attractions, including the Great Orme Copper Mine in North Wales, which is the only Bronze Age copper mine open to the public in the world (Fig. 8), and the Dolaucothi Gold Mine in Mid Wales, where gold has been mined for nearly 2000 years. Some caves are open as show caves and kept in almost the same condition as when they were found (e.g. Dan yr Ogof (Fig. 9), Wookey Hole, Gough's Caves in Cheddar Gorge, etc). There are trails (e.g. www.wales-underground.org.uk), while the Geologists' Association and many museums organise guided walks. In Northern Ireland the ESCR home page lists 20 of their sites that can be visited in country parks and nature reserves.

Coherent site-specific management planning is necessary to preserve the features that justify the site's designation. A management plan relies on documentation of the site, based on field observations, sedimentary logs, sketches and photographs, and an understanding of the factors that affect the site. The idea is to identify those features of primary interest and to keep them in a condition beneficial for future understanding of the site and keeping it in a 'favourable conservation status'. Changes to the overall quality of the site can be recognised by examining the factors that directly affect a site by utilising measurable characteristics or qualities of the core features. This acts as an indicator of the need

Figure 7 Capel Horeb Quarry in Mid Wales, famous for its Silurian early land plants, is owned by the British Institute for Geological Conservation.

Figure 8 The entrances to the Bronze Age copper mines on the Great Orme, Wales.

Figure 9 Inside Dan Yr Ogof caves in South Wales.

for remedial work. Regular site monitoring needs to concentrate on the core features for the whole process to function efficiently.

There is, however, one potential conflict of interest that should be mentioned here. The Environmental Protection Act 1990 Part II A 2000 introduced a new regulatory regime for identifying and remedying contaminated land and particularly includes old mines and mine dumps. Some of these are SSSIs because of their rare minerals.

Regionally important geological sites (RIGS)

Pre-GCR SSSIs that had not come up to the GCR standard were due to be de-scheduled, but these, together with other sites that, although not of national importance in a purely scientific sense, could fulfil an important local role for education, recreation, and/or geotourism. The concept of the RIGS came from this consideration and, although these sites are intended to serve local needs, RIGS Groups are encouraged to follow the general guidelines laid out in the original Nature Conservancy Council's Geoconservation Strategy document that was published in 1990. This suggests that RIGS should be selected according to their value for:

- educational fieldwork in schools, colleges and universities;
- scientific study by both professional and amateur earth scientists;
- understanding the historical development of earth sciences;
- and aesthetic qualities, particularly in relationship to promoting public awareness and appreciation of the earth sciences.

Emphasis should also be given to vulnerable sites, sites with extensive exposures and underground sites. Although RIGS are non-statutory they are included in RIGS registers held by local government planning departments so that their geological value can be considered in any development application that would affect the site. See Burek (2008) for details of the history of RIGS in Wales.

There are no comparable RIGS groups or programmes in Northern Ireland. Instead the ESCR programme now includes the identification of locally important sites.

International designations

International initiatives that are important for geological conservation are World Heritage Status, Geoparks and Geosites.

The United Nations Educational, Scientific and Cultural Organization (UNESCO) encourages the identification, protection and preservation of cultural and natural heritage around the world considered to be of outstanding value to humanity. These are called World Heritage Sites and since earth science sites have been accepted for World Heritage status, two sites in the UK have been so designated: 'The Giant's Causeway and Causeway Coast' (Fig. 10) in Northern Ireland (1986) and 'The Dorset and East Devon Coast' (2001). For further information on geological site designation under the 1972 UNESCO World Heritage Convention see Boylan (2008).

Geoparks are areas that not only have a rich and special geological heritage, from both national and international perspectives, but also have sustainable economic development strategies. European Geoparks have been designated since 2000 and a worldwide designation of UNESCO Geopark or World Geopark since February 2004. Such designated areas rank alongside the Biosphere Reserves of UNESCO's Man & Biosphere (MAB) programme. Currently there are 17 European Geoparks and 25 World Geoparks. 'Marble Arch under Cuicalgh Mountain Park' in Fermanagh, the North Pennine Area of Outstanding Natural Beauty, the 1000 sq km of the Abberly and Malvern Hills, Assynt in Scotland and the Brecon Beacons in Wales are the only UK areas designated so far as a Geoparks. For further information on the history of geoparks see Jones (2008).

The International Union of Geological Sciences (IUGS) initiated in 1996 a project known as Global Geosites, with the aim being to complete a documented list of key geoscience localities and terrains. This project is being spearheaded by the European Association ProGEO with country-based working groups. The British Institute for Geological Conservation is currently identifying British candidate sites (Cleal *et al.* 1999). The inventory, based on thorough scientific assessments, will lead to a fully justified and documented list of sites that can be used to support geological conservation and initiatives promoting the conservation of key sites for the effective pursuit of both educational and research interests.

Conclusions

Geoconservation in the UK is reasonably well organised even though there are some regional differences. The Geological Conservation Review is complete and the publication of the

Figure 10 Columnar basalt on the foreshore at Giants Causeway.

themed volumes on the selection blocks almost complete. This must not be seen as a final list, however, because new sites will become available and many existing sites are under pressure through development or neglect. An interesting suggestion has been made by the Royal Society of London (2001) for establishing a scheme to identify near surface (i.e. not presently exposed sites) of national importance that might become exposed (at least temporarily) in the future. Such a national register of such 'sleeping sites' would, through statutory safeguards, allow field investigation when any of them were exposed.

One approach for ensuring greater site protection would be by having greater resources for maintaining and managing them. Another could be to take more sites into ownership by concerned parties, such as the government agencies, local councils or voluntary organizations. This could be especially important for inland quarries that have been abandoned for a long time and in danger of having their scientific interest obliterated through collapse and vegetation encroachment. The Royal Society in their paper also suggested that geological sites "deemed to be of international significance should be identified as such and then be maintained more closely."

It is, of course, critical that the public supports any geoconservation strategy. Unfortunately, the public's understanding of geoconservation is generally very poor compared to their general knowledge of animal, plant and habitat conservation. Active programmes to encourage the supply of educational material and the promotion of geotourism should improve the situation. Geotourism is, of course, important here for both SSSIs and RIGS, because provision of interpretive facilities and services for public access and understanding can serve as a means to conserve and promote geological and geomorphological sites (see Hose 2008 for more details).

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Slavery, sugar, and the Survey

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Abstract

The British Geological Survey traces its foundation to 1835 when Henry Thomas De la Beche (1796–1855) was employed on the Geological Survey of Cornwall. De la Beche was taken on following the completion of his geological mapping of Devon, a project which he had initially undertaken at his own expense. His income was derived from a slave-worked sugar plantation in Jamaica, but unrest associated with the imminent abolition of slavery and a collapse of the sugar market left him without the necessary funds to finish the Devon work and in 1832, he was compelled to request government funding to complete the project. The British Geological Survey, therefore, owes its origins, at least in part, to the abolition of slavery.

Introduction

In 2007, Britain marked the 200th anniversary of the abolition of the trade in slaves; 2007 also saw the celebration of the bicentenary of the founding of the Geological Society of London. The link between geology and slavery, however, is not just the sharing of that bicentenary year. Ten years after the foundation of the Geological Society, a young man from Lyme Regis was admitted to its membership on 6 June 1817. Henry Thomas De la Beche had just turned 21 and, having developed an interest in geology, was now in a position to pursue his hobby among the ranks of the geological elite. He had just inherited his family's Jamaican estate — a sugar plantation worked by slaves.

Henry De la Beche was to become one of the major figures in geology in the first half of the 19th century. With William Buckland and William Daniel Conybeare, De la Beche was the third member of what Hugh Torrens has called 'that great geological triumvirate of Lyme'. He was an active member of the Geological Society, and served as its President in 1847–49. He was the author of a number of influential textbooks (De la Beche 1831, 1834, 1835, 1851). He worked on the geology of south-west England (De la Beche 1822, 1826a, 1826b, 1829, 1839, Buckland and De la Beche 1835) and Jamaica (De la Beche 1827), and was involved in the first descriptions of marine reptiles from the Lias (De la Beche and Conybeare 1821). His legacy remains, also, in the institutions that he established. He effectively founded the British Geological Survey, and established the principle of government-funded science. He started the Museum of Economic Geology, which eventually became the Geological Museum in South Kensington, and is now part of the Natural History Museum. He set up the Royal School of Mines, now part of Imperial College London, and he established the Mining Records Office, now part of the Coal Authority. For his achievements he was knighted in 1842.

This paper will focus on the early period of De la Beche's life, looking at some aspects his work at this time but also at some of what we know of his personal life. Many of his letters and diaries are housed in the Department of Geology of the National Museum of Wales (Sharpe 1997a, Sharpe and McCartney, 1998). Where reference is made below to specific items in this collection, accession numbers are given in parentheses. A short biography of De la Beche based largely on this collection was published by McCartney (1977) and other modern biographical notes have been published by Secord (2004) and Sharpe (2004).

Family background and early life

Despite the French-sounding name, Henry De la Beche's family was English. The family name was originally Beach, but in 1790, Henry's father and uncle changed it, with royal approval, to De la Beche, claiming descent from an old Norman family of Aldworth in Berkshire. What evidence there is, however, suggests that the De la Beche line died out in the 14th century. It seems likely, though, that they retained the pronunciation 'beach' (Sharpe 1997a).

Henry De la Beche was born in London on 13 February 1796. His father, Thomas, was a soldier, a Brevet Major in the Norfolk Fencible Cavalry, when Henry was born. Henry's mother, Elizabeth Smith, was from Downham in Norfolk. Thomas was born in Jamaica in 1756 where his father, also Thomas Beach (1715–1774), was Attorney General and Chief Justice.

Henry's father inherited the sugar plantation of Halse Hall in the Parish of Clarendon about 45km west of Kingston in 1775, following the death of his maternal grandmother. This inheritance was subject to the payment of a lump sum of £12,000 each to his brother John and his sister Janet, plus annuities. This would be equivalent to about £1.16 million each today. By 1793, they were still owed the money and due to interest and other charges, the debt had now risen to £30,000, so Thomas mortgaged the property with Hibbert and Co., the West Indies merchants, in order to make the payments.

In 1800 — by now he was a Lieutenant Colonel — his regiment disbanded and he took his wife and the four-year-old Henry to Jamaica. But while they were there, on 1 June 1801, Thomas De la Beche died. Henry was brought back to England by his mother, but the journey home was not without adventure. On 10 August 1801, they were aboard one of six English ships wrecked by the same storm on the reefs of Great Inagua at the southern end of the Bahamas.

Henry had a fairly peripatetic childhood and education. On return from Jamaica, he was sent to school in Hammersmith in 1802, then Keynsham in Somerset in 1805 and then Ottery St Mary in Devon in 1808. At some point during this period his widowed mother married a Henry Metcalf and this may have led to the move to the West Country.

In 1810, at the age of 14, Henry was enrolled in the Military College at Great Marlow in Buckinghamshire, presumably to follow in his father's footsteps with a career in the army. But his time there was short, just 18 months. He seems not to have taken to military life, and he was dismissed on 8 October 1811 for insubordination. Any plans for an army career were brought to an abrupt end, as was his formal education.

As you might expect, the manner of his departure from Military College was certainly not something that De la Beche talked about in later life. His friends and colleagues were aware that he had attended Great Marlow, but they seem to have assumed that he had been commissioned and had then given up a military life after the peace of 1815 (Hamilton 1856). With many of his geological contemporaries having been either to Cambridge or Oxford, or in the army, this may have been a misconception that De la Beche was reluctant to correct. It remains uncorrected even in some modern biographical dictionaries (Challinor 1994).

OUGS Journal 29 (2) Symposium Edition 2008, 88–94
© OUGS ISSN 0143-9472

By the time De la Beche had been sent down from Great Marlow in the autumn of 1811, his mother had moved once more, this time to Dawlish and he joined her there. A year later they moved to Charmouth, and then finally to Lyme Regis. At some stage, she had lost her second husband, Henry Metcalf, and had now married her third, William Huddle Aveline of Lyme Regis. The house in which they lived still stands at 54 Broad Street in Lyme and is currently occupied by a branch of Lloyd's Bank. This move to Lyme in 1812 gave De la Beche, at the age of 16, his first settled home, and afterwards he was to style himself 'of Lyme Regis'.

Early interest in geology

We assume that this is the period when De la Beche's interest in geology first develops. It may have started earlier, at one of the schools he attended in the south-west, or perhaps at Great Marlow, but at any rate, this was the time when he certainly learned his geology. He seems to have been well read, judging by references in his early journals to the published works of British and continental geologists. He certainly had a copy of Parkinson's *Organic Remains* in 1813.

And of course, he knew the Annings, the widowed Mary (senior) and her two children Joseph and Mary. Joseph was the same age as Henry, and Mary was three years younger. In 1811, the year before De la Beche moved to Lyme, Joseph found a large ichthyosaur skull, and when the rest of the skeleton, 17ft (5.2m) long, was extracted from the cliffs between Lyme and Charmouth, in early November 1812 (Howe *et al.* 1981), De la Beche was probably in the town. While he may not have been present when that famous specimen was excavated — or maybe he was? — Henry certainly went fossil collecting with Mary Anning between about 1812 and 1818.

Social status, marriage, Mary Anning

Despite the mortgage on the Jamaican estate, when De la Beche came of age in 1817 it still provided him with an annual income of £3,000, perhaps about £169,000 today. He now had the wherewithal to indulge his hobbies. Not only was he collecting fossils himself, but he was buying them from other collectors; he could afford the hefty subscription to the Geological Society; and he could buy himself a yacht, which he proudly sketched in his journal (Fig. 1). It seems that the young Henry developed a bit of a reputation in Lyme through his fondness for entertaining young ladies aboard his yacht. A local satirical poem of the time, *The Lymiad*, calls him 'Sir Fopling Fossil' and refers to his paying more attention to the female guests he has aboard than to the safe navigation of his boat. His mother is also mentioned in the same poem, where she is referred to as 'Madame Trois-maris' (Fowles 1982).

We have a portrait of him from around this time, and it is probably a good likeness (Fig. 2). From his passport we know that he had a high forehead, and an oval face, and we know that he was 5ft 8½in tall (NMW84.20G.D2246). From a later description (in 1836), we are told that his hair was brown and had a tendency to curl, and that he had brown eyes (Pym 1882). We even know his weight, at least in the spring of 1816, when he was weighed by the gunner at Fort Augustus in the Scottish Highlands — 151lb, just under eleven stone (De la Beche diary GSM1/830, British Geological Survey archives).

A question that often arises when Mary Anning and Henry De la Beche are mentioned is just how well did they know one another?

Figure 1 De la Beche's sketch of his yacht at Lyme (NMW84.20G.D341).

Figure 2 Henry De la Beche c. *1819 (© National Museum of Wales).*

Even allowing for the young De la Beche's reputation for the ladies, there are two issues to consider here. First, their ages: De la Beche probably first met Mary when he was 16 and she was just 13 years old. However, by the time De la Beche was 21, Mary had turned 18. De la Beche married in November 1818, so any relationship at this time would have had to have taken place sometime before that, when Mary was 16 or 17. It is worth remembering, though, that before 1837, the minimum legal age for marriage was 14 for boys and 12 for girls.

But the big barrier is the difference in wealth and class. Hugh Torrens has pointed out that from at least 1811 until at least 1816, the Annings were on parish poor relief (Torrens 1995). De la Beche, on the other hand, was heir to a reasonably wealthy Jamaican estate. So it seems unlikely that Henry and Mary had any relationship at that time. However, there was one further opportunity. By the mid 1820s, De la Beche was separated, and Mary was arguably approaching the height of her fame. Class and wealth may have been less of an obstruction to a liaison. It was also at this time that De la Beche arranged for a London naturalist, George Brettingham Sowerby, to sell specimens in the capital on Mary's behalf. W. D. Lang in a 1956 paper in which he published extracts from the journal of Anna Maria Pinney, suggests that there is just a hint that Mary Anning sometime between 1820 and 1830 "formed an attachment which came to an abrupt end" (Lang 1956). So there is still scope (but no evidence) for more scandal and gossip-mongering about Mary and Henry.

Ichthyosaurs and plesiosaurs

Living in Lyme, and fossil collecting with Mary Anning, it was perhaps natural that De la Beche would develop an early interest in the marine reptiles in the Dorset Lias. He had several ichthyosaurs in his own collection and recorded in his diary that there were at least three different species. In March 1819, De la Beche read a paper to the Geological Society on the geology of the Dorset and Devon coast. In this paper, incorporating notes from his diary, he refers to three species of *Ichthyosaurus*: *communis*, *platyodon* and *tenuirostris*, "reserving for a future communication by the Rev W. D. Conybeare and myself the reasons for so naming them, as well as a detailed account of the differences in their teeth." (De la Beche 1822).

Membership of the Geological Society may have brought De la Beche into contact with William Daniel Conybeare (1787–1857) and that other geologist with strong Lyme connections, William Buckland (1784–1856). But it is perfectly possible that De la

Beche had met either or both of them previously as they were frequent visitors to Lyme. Both were older than De la Beche, Conybeare by nine years and Buckland by 12.

Conybeare read their joint paper at a meeting of the Geological Society on 6 April 1821. De la Beche was not present, as he was doing fieldwork in northern France. In this paper, they recognised that the specimens they had seen also included the isolated bones of another new animal, which they named *Plesiosaurus* (De la Beche and Conybeare 1821).

During the course of his research on ichthyosaurs, De la Beche visited Bristol to view collections several times in 1817 and 1818. And it would seem that on one of these visits he met Letitia Whyte, the woman who became his wife.

Letitia Whyte was the daughter of Captain Charles John Whyte of Loughbrickland, Co. Down, Ireland. He was a catholic and his wife Anna Ross-Lewin was a protestant. He had adopted her religion, so his father disinherited him when he married, and they were never well off. Letitia was born in 1801 and was only two years old when her father died. Her mother left Ireland soon after and moved to Bristol with Letitia and a newly-born baby, Charles John. Late in 1804 she married John Lewis Auriol of Clifton in Bristol.

In 1806 Auriol was involved the construction of the Assembly Rooms in The Mall in Clifton. This development, which was completed in 1811, included a hotel. Auriol fell into financial difficulty (mainly because the architect, Francis Howard Greenway (1777–1837), was declared bankrupt, convicted of forgery and transported to Botany Bay, where he ended up as one of Australia's most famous architects. So again, Anna found herself not as well off as she might have hoped.

At some stage, perhaps in 1817 or early in 1818, a handsome young geologist, the owner of a Jamaican estate, may well have wandered into the Auriol's hotel. With a daughter of about 17, it may not have been far from Anna's mind that there would be certain advantages in a match. Letitia and Henry married in St Andrew's Parish Church in Clifton on 22 November 1818.

Travels in Europe

In July 1819, De la Beche, Letitia and her mother set off on a year-long visit to the continent. During this trip De la Beche established contacts with the leading naturalists in France and Switzerland, viewed collections, studied Alpine geology, and even attempted an ascent of Mont Blanc. Letitia was four months pregnant when she left England, so this may explain why she and her husband were accompanied by her mother. Perhaps also it was apparent to Letitia that she was going to be left on her own for considerable periods during the tour. Before he set off from Geneva on one of his spells of fieldwork, Letitia wrote in his journal:

> "My dear dear Henry Pray make haste back to Poor me September 19th 1818 [The date probably ought to be 1819] Letitia – Write to me if possible, and try to be back by Saturday the latest." (NMW84.20G.D345)

While they were in Switzerland, Letitia gave birth to their daughter Elizabeth, usually called Bessie. She was born on 2 December 1819 in Geneva. They returned to Lyme in July 1820, and Bessie was baptised there on 25 November. They took up residence at a large house, The Grove, on the outskirts of Lyme.

Figure 3 Halse Hall in 1923, probably little changed from when De la Beche was there 100 years before (from a photograph in the Department of Geology, National Museum of Wales).

Jamaica

In November 1823, Henry set off, alone, to visit his estate in Jamaica and did not return until January 1825. He had not been back to Jamaica since the visit in 1800–1 when he was a child. Why he went alone is a matter for some conjecture, but it may be simply that the long sea-crossing and the climate of the island were considered unsuitable for Letitia and their three-year-old daughter.

The estate, in one of the main sugar-cane growing areas of the island, comprised the great house, Halse Hall, 4,482 acres, and 207 slaves (Figs 3, *above*, and 4, *opposite*).

On arrival at the estate he noted in his diary:

> "Jan 7–12 1824
> At Halse Hall, examining the state of the negroes and other matters.
> Their condition is nothing like what I was led to expect, from statements on the other side of the Atlantic, though many things no doubt require gradual alteration, yet the general condition of my own negroes is anything but bad, the huts they live in they prefer vastly to any you can erect for them, their provision grounds furnish them with fruits that would make a turtle eating London Alderman's mouth water, the surplus of which they carry to market and sell, with the money they buy themselves finery &c.
> As far as physical comforts extend they are vastly better off than the peasants of most European countries I have visited." (NMW 84.20G.D352)

De la Beche was a reforming slave owner who banned the use of the whip on his estate, introduced religious education for his slaves, and issued medals as a reward for good conduct. But these changes put him at odds with many of the other slave owners on the island. He also found himself attacked by the abolitionists, including his friend Conybeare, for the very fact that he owned slaves, although as he later pointed out this was due to "the accidental circumstance of inheriting West Indian property" (De la Beche 1825) and it did not follow that as a slave proprietor he was a supporter of slavery.

Sugar production in Jamaica peaked in 1815 and through the 1820s competition from Cuba increased. Falling income from his estate may have kept De la Beche in Jamaica longer than he had originally planned. In July 1824 he wrote to Conybeare:

> "Much as I desire speedily to return to my native and cool land, the present depressed state of West Indian produce and West Indian affairs generally, has so diminished my command of the needful that I cannot exactly state when that may be." (NMW84.20G.D358)

As well as getting to grips with the management of his estate, he made the most of his first few months in Jamaica studying the geology of the island. His observations were reported in letters to Conybeare who, in reply, kept De la Beche up to date with the geological news from home.

Jamaican geology and slavery

On his return, De la Beche read the first part of his paper 'Remarks on the Geology of Jamaica' at the Geological Society on 2 December 1825 (De la Beche 1827). When it was published it contained a geological map of the eastern part of the island, including the rugged and difficult Blue Mountains. Through this work De la Beche is regarded as the father of Jamaican geology, and seems for many years to have been better known in Jamaica than in the UK.

He also published a book of his observations on the state of slavery in Jamaica (De la Beche 1825). This was purely a descriptive account, he said, to place on record some of the facts about the lives of the slaves and the way estates were run, as he had witnessed them. He thought that some accurate facts might contribute to the debate on abolition:

> "I entered on this investigation with a sincere desire to ascertain facts, and with no other predisposition than the dislike of slavery natural to every Englishman, and which I trust the accidental circumstance of inheriting West Indian property does not necessarily obliterate …; but the question … is not whether slavery in itself be the object of our love or hate, but how the existing state of things in our West India colonies can be changed with justice and safety to all the parties interested."

De la Beche favoured a gradual process of abolition and was concerned that immediate and sudden release of slaves would cause the loss of his estate and his income.

When he returned from Jamaica, all was not well at home; in September 1825, De la Beche and Letitia formally separated, and they divorced in the ecclesiastical courts in 1826. This was not a divorce in the modern sense, as that required an Act of Parliament at that time, so neither party was free to remarry. Their daughter Bessie remained with her father, and lived with her grandmother in the house in Broad Street in Lyme when De la Beche was away.

Letitia's story

Letitia's story now reads like an episode of a soap opera. Shortly after their separation, Letitia ran off with Major-General Henry Wyndham, an illegitimate son of George O'Brien Wyndham, third earl of Egremont. Henry Wyndham too was married and separated. In 1826, Letitia moved in with Wyndham to a large house in Mayfair, where she hosted his dinner parties and was, in all but name, his wife for 14 years.

Having set up with Wyndham, she forfeited any settlement that was made for her by De la Beche. There was some concern that if Letitia and Wyndham were to part, she would be destitute so the Earl of Egremont lodged £27,000 with Wyndham's bank for Letitia's benefit. However, Letitia allowed Wyndham to take £20,000 of it to settle his gambling debts, trusting that if anything were to happen, he would provide for her.

In 1838, Letitia heard from her family in Ireland that her cousin and aunt were destitute, and she persuaded Wyndham to allow them to live with her and Wyndham in London. But within two years, she was asking Wyndham to give them an allowance and remove them as they were "upsetting the happiness of the house". Her cousin had begun a relationship with Wyndham. This difficult situation dragged on for a further two years until, at 9 o'clock on 20 July 1842, at the height of a thunderstorm, Wyndham had Letitia thrown out of the house. She spent the night in a "miserable railroad station-house" at Paddington, and next day arrived at her mother's house in Cheltenham.

Figure 4 De la Beche's sketch of slaves at Halse Hall (from De la Beche 1825).

Her cousin broke open Letitia's trunks, took her clothes and was seen around town wearing Letitia's cloaks. She began to remove all trace of Letitia from the house: she had a bust of Letitia returned to the sculptor; a portrait of Wyndham and Letitia was sent back to the artist to have Letitia painted out; and other portraits of Letitia and of her mother were burnt.

We know so much about this because Letitia's mother published an account of her

daughter's situation (Auriol 1843). Although Letitia had been separated from De la Beche for 16 years, when De la Beche was knighted in 1842, she immediately assumed the title of Lady De la Beche. Her mother's pamphlet, *Statement and Correspondence Consequent on the Ill-treatment of Lady De la Beche by Major-General Henry Wyndham, Compiled by her Mother, Anne Auriol*, must have been hugely embarrassing for De la Beche and his daughter, Bessie, who had by now married into a prominent Swansea family. To compound the embarrassment further, the pamphlet also made reference to Letitia's unhappy marriage to De la Beche, including the publication, in full, of a private and personal letter written by De la Beche to Letitia when they separated in 1825. Quite why their marriage was such an unhappy one is not clear, but it may have been that long periods of separation while De la Beche pursued his fieldwork were more than Letitia could handle.

Letitia ended her days in Ireland in poverty in 1844.

De la Beche found that the strain of the separation and divorce affected his health. He spent the next two winters on the continent, mainly in Italy. However, he was fit enough to climb Vesuvius during an eruptive episode, and to conduct the fieldwork that resulted in papers on the geology of Nice and La Spezia.

Geological theory

1830 saw the publication of the first volume of Charles Lyell's *Principles of Geology*, a work that De la Beche viewed as completely contrary to his own empirical view of how the new science of geology should be proceeding. De la Beche believed that the science was still too young for grand theories, and that this was still the time to be collecting the facts. To this end he published, in 1830, *Sections and Views Illustrative of Geological Phaenomena* (De la Beche 1830). This was merely a collection of forty plates with descriptive captions aimed at presenting a variety of geological features, maps and sections, with no attempt at a synthesis or theoretical interpretation. In his preface to this work, De la Beche was blunt about geologists too keen to theorise:

> "Generally speaking, geologists have been much more intent on making little worlds of their own, than in examining the crust of that which they inhabit."

Critical of Lyell's theoretical approach, De la Beche responded in 1831 with *A Geological Manual*, the first in a series of influential textbooks he was to write. Summarizing the state of geological knowledge and research at that time, *A Geological Manual* ran to three editions in Britain between 1831 and 1833, American editions, and was also translated into French and German.

De la Beche the illustrator

De la Beche drew all 40 plates of *Sections and Views* himself, and he is recognized today (and by his contemporaries) as a very able geological artist. He used his skill both in his formal publications and informally in a number of sketches and cartoons through which he commented on developments in the science (Rudwick 1975; McCartney 1977).

In early 1830 De la Beche produced one of the most significant and influential images in geology. *Duria Antiquior (An Earlier Dorsetshire)* was the first ever attempt to portray the full fossil fauna and flora of an area at a particular point in geological time (Fig. 5). Not only did it show all the elements of the fauna going about their daily business of eating one another in the early Jurassic of Dorset, but it was also remarkable too for its viewpoint, showing the scene both above and below water, as though we are in a Jurassic aquarium (Rudwick 1992).

There are three species of ichthyosaur present in the scene, the three described by De la Beche in 1819: the small *communis*, the slender-snouted *tenuirostris* — shown eating a *Dapedium* — and the large *platyodon* (now *Temnodontosaurus platyodon*). The image also draws on De la Beche's experience of Jamaica, which is clearly evident in the vegetation (although perhaps not in the palm tree growing in mid air!). Throughout the carnage, coprolites are being actively produced from the nether regions of most of the beasts in the scene.

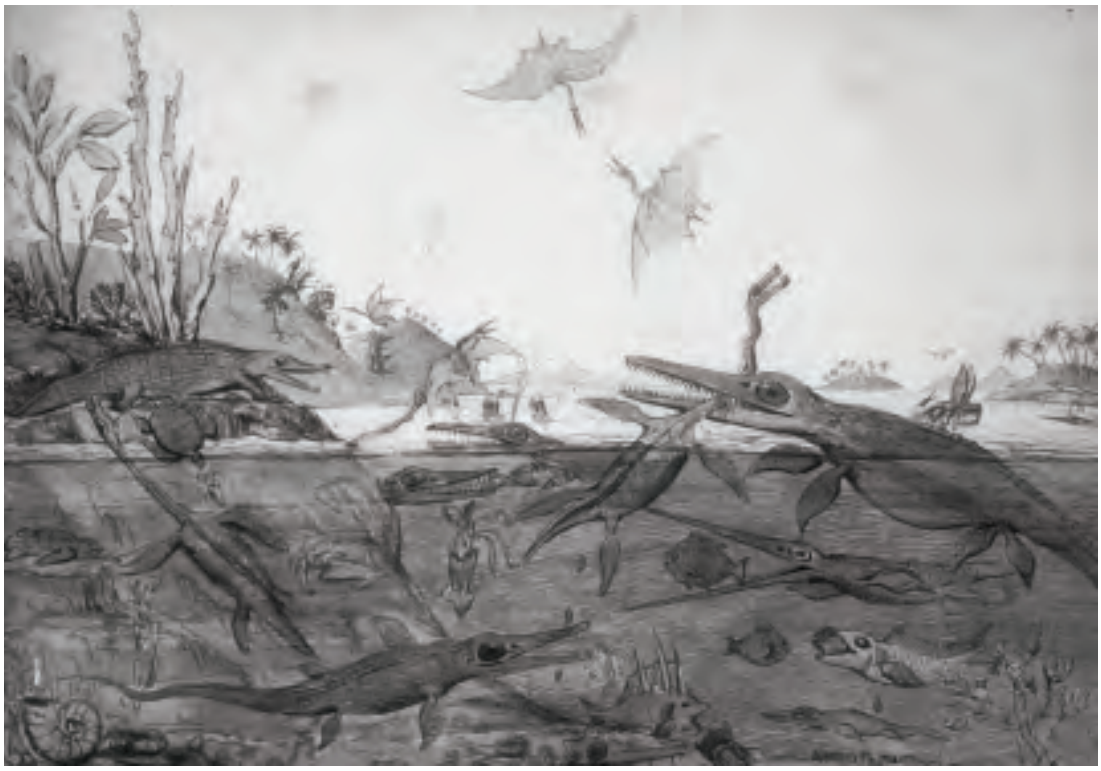

Figure 5 Original watercolour of Duria Antiquior *by Henry De la Beche (NMW84.20G.D368).*

It is, in many ways, a homage to the discoveries of Mary Anning in the Lias rocks of Lyme: the ichthyosaurs of 1811 onwards, the plesiosaurs of 1823, the coprolites of 1824 and the pterosaurs of 1828. The significance of this has been pointed out by Hugh Torrens (1995) who has found that the drawing and the lithograph based upon it,

were produced in order to raise money for Mary and her family, who had fallen on hard times once more. Copies of the lithograph sold for £2/10/0, which may be equivalent to about £180 today.

With its blood and gore, and active coprolite production, William Buckland, of course, loved it, and used it in his classes at Oxford. Buckland wrote to De la Beche:

> "I have a capital class & your Duria has contributed to its numbers & my entertainment of them." (NMW 84.20G.D182)

He also urged De la Beche to prepare two or three more such restorations but as far as we know, he never did.

The *Duria Antiquior* was used, too, in Cambridge where Adam Sedgwick (1785–1873), Professor of Geology, had the lithograph copied into a large oil painting, but the more sensitive souls at Cambridge were spared the indelicacy of the coprolites.

Today we see so many of these kinds of reconstructions of life in the past that it is difficult to imagine the impact this image must have had. To go from the bones and skeletons, not only to flesh out how the living animals looked, but to show them living their lives and interacting with one another was a major step.

From this time onwards, such scenes became standard in popular books about palaeontology, and the evolution of these reconstructions can be traced right through to the moving image and to today's computer-generated reconstructions of the Hollywood film *Jurassic Park* and the BBC's natural history production *Walking With Dinosaurs*.

Mapping Devon and the foundation of the BGS

But De la Beche's major project of 1830 was his geological mapping of Devon. This was probably going to be no different from his other geological fieldwork, with the resulting map published perhaps in the Geological Society's *Transactions*. But the income from his Jamaican estate had continued to diminish. Sugar prices had continued to fall, as they had done since 1798. Following the abolition of the slave trade in 1807, slaves were anticipating full emancipation in the 1830s and there was unrest in Jamaica with a major slave revolt from December 1831 to January 1832. De la Beche was beginning to feel the pinch.

In 1832, part way through his mapping project, he felt he could no longer carry the cost of his Devon mapping. As he was working with Ordnance Survey maps, he wrote to the Master General of the Board of Ordnance to say that he:

> "had … been defeated by the failure of certain funds … I am induced therefore to offer to your Honble. Board the fruits of my labours at a price that I am well assured will be considered very moderate knowing as I do that it will be much below the sum they will have cost me when completed." (McCartney 1977)

In his request to the Board of Ordnance he not only explained the economic advantages to the nation of geological maps, but also the net profit which the Board could expect from their sale. De la Beche showed for the first time his understanding of the official mind, which he used to great effect in his later dealings with the government. His application was successful and he was given £300 (equivalent to over £22,000 today) and appointed Geologist to the Trigonometrical Survey of Great Britain.

Once the eight sheets covering Devon had been completed, De la Beche proposed to the Board of Ordnance that he would be happy to devote his time "to the geological examination of another portion of the country" (McCartney 1977). With the support of Buckland, Sedgwick and Lyell, in 1835 funding was made available to extend the mapping into Cornwall. The establishment of the Geological Survey of Cornwall is taken as the foundation of the Geological Survey of Great Britain, now the British Geological Survey, and De la Beche became its first Director.

Professional geology

The formation of the Geological Survey in 1835 was timely, not only for British science (and the economy), with expanding industrialization and urban development demanding raw materials, but for De la Beche personally. For the first time he was no longer solely dependent on his Jamaican income. This paid employment took De la Beche from the ranks of the gentleman geologists with private means and turned him into a professional government scientist. Geology had taken a new direction.

Were it not for the collapse of the Jamaican sugar market and the unrest associated with the abolition of slavery leading to the failure of De la Beche's private income, the history of the foundation of today's British Geological Survey could have been very different.

The Devon mapping in the autumn of 1833 had not been all work and no play for De la Beche, as is clear from the arrival of an illegitimate daughter, Rosalie Torre De la Beche (Sharpe 1997b). His will records her birth as being in either June or July 1834 in Taunton, so clearly he was elsewhere at the time. We have no idea who the mother was. Nevertheless, Bessie accepted her as a sister and the two were close. We have photographs of the two girls with their father, taken in Swansea in 1853, less than 18 months before De la Beche died (Fig. 6).

Figure 6 Henry De la Beche with his two daughters, Rosie (standing) and Bessie in Swansea in 1853 (NMW84.20G.D422.1).

Bessie had travelled with her father through much of the Cornwall mapping and when he moved to Swansea in December 1837, she went with him. The following year she married Lewis Llewelyn Dillwyn (1814–1892), the second son of Lewis Weston Dillwyn the MP for Swansea who was a long-time friend of De la Beche (Sharpe 1985).

By one of those strange quirks of fate, this marriage brought together the descendants of slave owners on one side and of Quaker abolitionists on the other (Painting 1987). William Dillwyn, a founder member of the Society for the Abolition of the Slave Trade, and who was active with Thomas Clarkson and William Wilberforce in the abolition campaign, was Lewis Llewelyn Dillwyn's grandfather.

Acknowledgements

I would like to record my thanks to the late Paul McCartney on whose work so much of this paper is based; to the late John Fowles who over several years provided me with information about Georgian Lyme and *The Lymiad*; and to Jo Draper of the Philpot Museum for her help.

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Geochronological hits and misses: various attempts to determine the age of the Earth

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Introduction

In the last 150 years various scientists have devised various novel imaginative methods to determine the age of the Earth. Prior to this, theologians, men of learning, philosophers and many others have also considered the question. Today many geologists consider that we now know the absolute age of the Earth, and that its chronology is very ancient. Others disagree, and in the past these disagreements led to further scientific investigation. For geologists and others this debate was crucial in that the determination of the Earth's age is a fundamental question that ranks alongside that of how the Earth formed in the first place.

Creation beliefs

The earliest estimates of the antiquity of the Earth were devised by a number of different civilisations: the Greeks, the Maya, native Americans and Chinese, all of which had a creation story. The Chinese believed that Earth history was cyclical, each revolution taking approximately 20 million years. However, it is unclear from early writers how many cycles have occurred. Not every creation belief is framed in geological examples. Perhaps the first use of a recognisable geological fact was provided by the early Greek traveller Herodotus, who lived in Egypt. He was aware that the Nile delta was a site for the deposition of sediment and he estimated that it would take 5,000 years to fill up the Red Sea.

Biblical estimates

From the 1600s more than 200 estimates of the date of creation were published, although today it was that of James Ussher (Fig. 1) that is primarily remembered. The Bible provides a chronological framework of seven periods up to the birth of Christ: creation to the flood; the flood to the promise made to Abraham; the promise to the granting of the Ten Commandments; the Ten Commandments to the building of the Temple; the temple to the captivity of the Israelites; the captivity to their return to Israel; and finally the period from the return to the birth of Christ.

These biblical calculations were remarkably consistent, suggesting that the period from creation was approximately 6,000 years. Variations came about through interpretation of different biblical texts. Ussher, the Archbishop of Armagh, was a significant scholar, who on his death during the Commonwealth was the only person to be buried in Westminster Abbey. His chronology appeared in his *Annales Veteris Testamenti* of 1650, which was published in Latin and then translated eight years later as *The Annals of the World*. Ussher is often misquoted and what he actually wrote was that the Earth was created "upon the entrance of the night preceding the 23rd day of October in the year of the Julian calendar 710" (i.e. 4004 BC). Ussher's chronology is the best known of all the biblical chronologies simply because it was printed in the margins of the King James Bible, the authorised version.

Figure 1 James Ussher, Archbishop of Armagh.

Early empirical dates

Through the influence of the Royal Society a number of scholars produced empirical dates and figures for the age of the Earth. Edward Lhwyd was born in Shropshire in 1660 and became Keeper of the Ashmolean Museum in Oxford. He travelled extensively and augmented his salary by contributing to Camden's *Britannica*, which was a sort of 'rough guide' to Britain of the time. In Ireland he produced a dictionary of the Irish language and spent some time under arrest in Brittany, accused of being an English spy. His chronology was derived at Llanberis Pass in Snowdonia where he observed large blocks of stone littering the valley floor. Having asked the local people how often these fell, and discovering that even the oldest people had not observed any fall, he deduced that the Earth must be very old, older than the biblical chronologers had calculated. We now know that the stone blocks are glacial erratics left behind following the melting of recent glacial ice.

It is not well known that Edmund Halley, best remembered for his description of the comet that bears his name, was interested in the hydrological cycle. He set up an observatory on St Helena and while there he was saw plenty of precipitation. In a short paper read to the Royal Society in 1715 he argued that calculation of the rate that salt entered a closed water body could be used as a proxy to date the Earth. So if you could measure the amount of sodium and other salts within a body of water, and then go back 100 years later and measure it again, this would provide the rate of salination, and from this data one could then work out how old that body of water actually is. He pointed out that the Earth may well be found to be far older than some had imagined.

The cooling Earth

In France the Compt de Buffon was an influential scientist as the Curator of the Jardin des Roi in Paris. He too became interested in the age of the Earth and thought that, as the planet was originally molten, its age could be calculated through examination of its cooling rate. On his estate at Dijon he constructed a forge, which he fuelled with charcoal produced from timber from his own forests, and in this forge he heated up a series of iron spheres of various diameters up to a maximum of five inches. Once red hot he allowed them to cool down and found the largest could be held in the hand after 3hr 52min. Extrapolating the figures for the dimensions of the Earth he argued that it had been formed about three million years ago. Later, because of religious considerations and opposition from academics in the Sorbonne, Buffon reduced his chronology to about 75,000 years.

OUGS Journal 29 (2) Symposium Edition 2008, 95–7
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Figure 2 James Hutton.

Development of stratigraphy

From the 1650s onwards thinkers began to realise that the rocks on the surface of the Earth displayed a somewhat regular arrangement. Nicholas Steno demonstrated how caves and dipping strata in Tuscany were formed, and said that beds could be identified over distances. The Italian Giovanni Ardunio, among others, wrote on the division of mountains into primary, secondary, and tertiary packages. None of these early stratigraphers provided a date for creation, but must have recognised the antiquity of the successions they described. So too did the Scot James Hutton (Fig. 2), who noted that Earth history was cyclical and unending. Following publication of his *Theory of the Earth* (1795), he backed up his conjectures through observations made in the field, where he recognised gaps in the rock record, such as the unconformity at Siccar Point. The stratigraphical laws devised by William Smith enabled geologists to place distinctive packages of rock into their correct relative positions. Thus the genesis of the modern geological column had begun in the 1830s and 50 years later most of the periods were well-defined. However, their absolute ages of the boundries between them was not known.

Denudation and sedimentation

In 1860 John Phillips, the nephew of William Smith, considered that he could make an estimate of the thickness of the complete sedimentary pile seen in the geological record, work out the rate at which it was deposited and derive the age of the Earth. His calculations were not very accurate, and yielded estimates of between 20 and 400 million years. The difficulty was in the determination of the thickness of the sedimentary pile, which different authors gave as between 12,000ft (3,658m) and 350,000ft (106,680m), thus producing a great deal of error.

The opposite of sedimentation is denudation, and it is perhaps surprising that Charles Darwin should have used this geological process to date the formation of a geological feature in south-east England. In his *Origin of Species* (1859) on pages 285–6 the argued that the Weald, which is a dissected anticline, would have taken 300 million years to reach its present form. He said that denudation had removed an inch of sediment per century, and his estimate for the age of the Mesozoic provided him with the time needed for natural selection to occur.

The cooling Earth revisited

Darwin's ideas were rejected by many eminent scientists, of whom the Belfast-born physicist William Thomson (later Lord Kelvin) was the best known. He re-visited the idea of the cooling Earth, and following experimental work in Glasgow produced a geothermal gradient for the Earth. In 1863 he concluded that it had taken the Earth 98 million years to cool to a temperature where plants could grown on its surface. He later carried out further calculations and reduced his estimate to 20 to 40 million years, and also looked at the time the sun had been shining and used that as a proxy for the age of the Earth. Thomson's ideas held sway in the scientific community for about 30 years.

Salination revisited

Thomson's/Lord Kelvin's scheme was consigned to the backwaters of science as a result of a revisit of the idea of oceanic salination rates. In 1897 John Joly of Trinity College, Dublin purchased a yacht to celebrate his appointment to the Chair of Geology and Mineralogy. He was a keen sailor and one day while on the Irish Sea realised that if he was to measure the rate at which sodium gets into the ocean, and you assumed that the ocean was originally fresh, you could come up with the age of the Earth. He was unaware of Halley's earlier paper and considered his scheme to be novel. Taking oceanographic information provided by John Murray and the *Challenger* expeditions of 1872–6. Joly wrote that his method gave an age of the oceans as 100 million years. Joly was convinced that this was equivalent to the age of the Earth, and he was so confident of his methodology that he said that nobody would question his conclusions.

Radioactivity and geochronology

In the same year as Joly's pronouncement, radioactivity and X-rays were discovered. Joly soon became interested in the subject and many of his publications from the early 1900s document the volumes of radioactive elements such a radium and thorium in various rocks and sediments. He also examined pleochroic haloes in various granites, and noted that these dark rings, produced by the decay of radioactive particles contained in zircon grains, themselves trapped in mica, might provide a dating tool. He considered, as did the physicist Ernest Rutherford, rings that were more dense and that had a larger diameter to be older than those of smaller diameter and less intense halos. Later, when it was realised that radioactive elements contained various isotopes, Joly's conclusions were shown to be incorrect.

Radiogenic elements were utilised in the first decade of the 20th century as dating tools by a young English geologist. Arthur Holmes had almost single-handedly produced the absolute timescale with which geologists are now so familiar. In 1911 he published a paper that suggested that the Earth was really much older than the scientists had thought at the time. He took the concept of the half-life — the breakdown of radioactive elements to half of their volume over a set time period — and realised that the proportions of the parent and daughter elements found in rocks could provide an absolute age of the sample. In 1911 he said that the Precambrian Period was 1,640 million years old. By 1935 he had increased his estimate to 3,000 million years. These dates were problematic for the physicists, however, who held that not even the universe was as old as this. Eventually the chronology of the Earth and of the universe would be reconciled.

Later Holmes and Georges Houtermans independently came up with a graphical scheme where various decay ratios could be plotted on a graph to produce a straight line or isochron, the slope of which gave the age of the material graphed, and by 1947 the absolute age of the boundaries between geological periods was known (Fig. 3, *opposite*), but still the age of the Earth remained illusive.

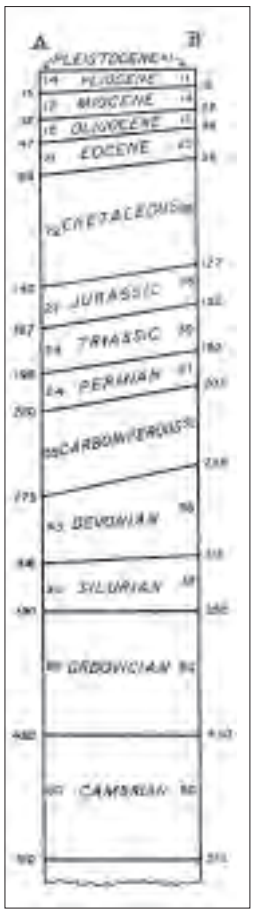

Figure 3 Geological Timescale with absolute dates published by Arthur Holmes in 1947.

Mass spectrometry and meteorites

In the 1950s the invention of the mass spectrometer enabled scientists to work out more precisely the ratios of various radioactive elements. Clair Patterson investigated the ages of a number of meteorites (Fig. 4). He was interested in determining the proportions of non-radioactively derived lead (or primeval lead) and lead produced by radioactive breakdown from the uranium that they contained. This would provide an accurate age of the meteorites examined. Late one night in Chicago he analysed his samples in a mass spectrometer, which churned out a number of results. Patterson took out his pencil, scribbled some calculations, and concluded that the samples were 4,500 million years old. He was so excited about this that he drove to his parents' house and asked his mother to book him into the local hospital because he thought he was having a heart attack. Later he plotted these figures and included some results from terrestrial material and all the points were aligned on an isochron. In 1956 he published his seminal paper and showed that meteorites provided the actual age of the Earth: 4.5 billion years.

Figure 4 Canyon Diablo, Arizona meteorite (above) and Henbury meteorites (below). Examples of these were analysed by Clair Patterson.

(Author's note: This paper is a brief synopsis of my book The Chronologers' Quest: Episodes in the Search for the Age of the Earth *(Cambridge U. P., 2006) where sources can be found.)*

Book review

Farrant, A. R. 2008 *A Walkers Guide to the Geology and Landscape of Eastern Mendip* [book and map at 1:25 000 scale]. Keyworth, Nottingham: British Geological Survey

Farrant, A. R. 2008 *A Walkers Guide to the Geology and Landscape of Western Mendip* [book and map at 1:25 000 scale]. Keyworth, Nottingham: British Geological Survey

These attractive two book and map sets are very nicely presented in slip cases with the maps simplified and marked up with references to the accompanying books. Areas of particular interest have slightly larger scale maps (1:20 000) in the margins as well as the usual cross sections and stratigraphical information. There is also a useful relief map in the corner of each geological map that helps to make sense of the geology and terrain. There has been considerable effort here to simplify: for example, the descriptions of the beds in the stratigraphic column are fuller than normally seen with details of colour and fossils. As a keen walker and geologist I was very taken with them, as were the members of a Continuing Education class that I taught in Dorset.

However, although these are branded as 'walkers guides', I do feel that some geological knowledge is needed to make the most of them. Although there is a useful glossary at the end of each booklet there are a few parts of the text where assumptions are made! For example, the explanations and descriptions of 'pericline' are not perhaps so helpful to a novice: to that say it is a type of anticline and to label an illustration of a plunging anticline as a pericline is potentially a little confusing! The information is all there, but the reader has to work for it.

However, this is perhaps a little churlish as these packs are very attractive indeed. The booklets are full of interesting material and guide the walker around some lovely parts of the area with plenty of background information. Good (but small!) photos of the rock types and minerals and good material on the extractive industries here. The illustrations overall are good. I like the cross sections, aerial photographs and maps within the guide very much.

So, if you going to be in the area, I would get them! Ideal for OUGS members, I am just not sure that they are quite accessible enough to the complete novice.

— Jenny Bennett BA Hons (Open) MPhil PhD OU tutor

Summary remarks by OUGS President Dr Sandy Smith

Dr Alan Chapman's talk on Friday evening was an absolutely stunning talk, and set the tone for the whole weekend. I must admit that when I heard about what the subject of this Symposium was, I had mixed feelings about it. I wondered if it was going to be interesting. And, was I wrong! The whole weekend has been one of the most interesting OUGS Symposia I have been to. That may reflect the fact that I knew very little about the history of geology, and for that I apologise to people like Cynthia, who know a lot about it. It's a branch that I have, first, ignored, and, second, admit that I know little about. But what I have found is that it's connected into the history of the OU and also connected into my history. I found that I had been picking bits out of everybody's lectures and relating it to how it has affected me. And why I'm here is really due to what has been said this weekend.

We started with Alan Chapman's talk about William Buckland, who obviously was a towering figure. The nineteenth-century must have been an incredibly exciting time for geology and what struck me was that these geologists were just ignoring the Genesis idea that the Earth was created in 4004 BC, having realised that actually the Earth was much older than this. Whereas I thought that geology really started going with Darwin in 1859 from the *Origin of Species*. But, no, they were getting round this. They were going onwards — Alan said that they actually thought the Earth was vastly old. Well, they got that absolutely right. And he even made the connection with William Smith: William Smith had the practical information, the recognition that fossils identified strata — this was the real key to really understanding what was going on.

It also made me aware how much geology is tied up with UK history of geology. If it weren't for UK geologists, geology wouldn't really have got very far. Alan made the point that scientists, geologists, whatever they were — they weren't really 'geologists' at that age — were very broadly educated. They might have studied maths, arts, or medicine. It made me think that I've got a degree in geology and it's probably from, arguably — this is where I get things thrown at me — the best university for geology in the country, but my geology degree is actually in natural sciences, which was reflecting this broad education; and it's a BA, so this is coming down from the 19th century. OK my old university still is very old-fashioned like this, but it's still giving BAs in natural sciences. My research degree from that university is a Doctor of Philosophy, not science.

I like the idea of William Buckland hiring a train to do a field trip. Once, when I was working in the Cambridge University library, I found my way to something called the Tower, which had all the 19th-century items in it, and I was wondering what was going on in the 19th century — I think was very bored; I was trying to do anything but the essay subject obviously — and I went to look up the *Cambridge University Reporter*, which still continues; it tells you what's going on, what lectures there are, where they are, whatever. So as a student you buy the *Cambridge University Reporter*. I looked at a date a hundred years before the time — and I found a mention of a geology field trip. It said that the Woodwardian Professor of Geology invites his students to meet him outside the Senate House at ten o'clock on Friday, 1st of May, on horseback, where they would proceed to the sand pit at Ely, etc. So, they were doing it on horseback whereas Buckland was doing it by train — I think that seems a better idea, I must admit.

What was still in evidence, even with me in the late sixties, is that students wore academic dress. I had to wear academic dress to lectures —my gown went in my bicycle basket; and then I put it on when I went into a lecture. This was still part of the tradition. And what you could do then, and what we were actually taught to do, to identify some rocks, was to lick them. It's still the best way of telling mudstone from siltstone, but for health and safety reasons I can now no longer ask you to do that at Summer School. But it's tying us into that old method of teaching by finding out, in a practical way.

Cherry Lewis told us some very interesting things about James Parkinson. Like most people I only thought of him in terms of medicine. But she made the point that four out of 13 founding members of the Geological Society were medical men; and that medical men needed to know quite a lot about mineralogy, in particular, because they made medicines out of minerals. They had to grind up the right minerals. I'm not sure, but I was thinking that there's only one mineral that could possibly still be used that I'm aware of — which is kaolin. So I think they had to tell their kaolin from their illite and things like this. Parkinson really gave them the term geology in the general sense used today — which wasn't in general use until the founding of the Geological Society in 1807 — so good for James Parkinson. He also brought 'fossil' into present-day use too. He was a fossil expert, impressive for a medical person.

Ted Rose talked about the military connections of geology. Geological mapping was initiated by the military, and we get de la Beche as the first Geological Survey Director, and mapping. I'd always been aware of that, because the military used to fund some of my research. When I started doing marine research I got a lot of support from the American government — I initially didn't understand why, and then I realised what they wanted was the gravity field to launch missiles; if you don't get the right gravity field you don't hit Moscow, you hit New York.

Cynthia's talk about the women in geology was an absolute delight. I was looking around thinking that there are about 50% women, about 50% men here. That's reflecting the number of OU students doing geology, I think — I looked this up before I came — S260, the geology course, this year had 52% women in it, 48%, no 47% men — I don't now what happened to that other one per cent. Of the something like 30 research students in my department, again it's about 50–50. I was reminiscing with Cynthia, saying that when I was an undergraduate — about 40 years ago (don't pass that on) — I was the only woman out of 21 people in my final year doing geology. And we were both, Cynthia and I, saying how difficult it was to get some jobs in geology. You couldn't go on oil rigs; you couldn't go to Arab countries to work; and when I went for an interview with the Geological Survey I withdrew immediately afterwards — I thought I'm not going to work for that hide-bound lot. That was what it was at the time — but now it's changed. But that was a link very much into the past, of what it was like. And all the women who really were impressive in geology — Marie Stopes, as well as the people that Cynthia mentioned— had a lot of determination, and were very good indeed.

OUGS Journal 29 (2) Symposium Edition 2008, 98–9
© OUGS ISSN 0143-9472

When I went up to university, I wanted to be a physicist. But I ended up going to a university where you had to do three sciences in the first year, and I was the only person in my college studying geology. So I went to the library and got all the geology books out. And they had Gertrude Ellis's name on them, because she was a member of the college and when she died she gave all her books to the college library. So I began to think about Gertrude Ellis and — apart from that I like climbing mountains —that got me into geology. So I'm not a physicist, but a very happy geologist.

Bill Chaloner told us about Marie Stopes, who was obviously an absolutely dedicated palaeobotanist and a very good scientist altogether.

Alan Bowden told us about meteorites —using meteorites to reflect the history of geology And the OU is into meteorites.

Ian Gass — how many of you actually met Ian? [raising of hands among the audience] OK, that's about a half. If you met Ian you couldn't help but be affected by him. He was an absolute dynamo. I remember his 'bullshit' stamp. I got it on one thing I wrote. I remember going to Ian and saying, "you're wrong". Half an hour later we agreed to compromise; that is we agreed I wasn't wrong, but that what I wrote wasn't best way of writing it. Then Ian opened a bottle of gin, and about half a bottle later we were the best of friends; that was Ian. He was a real enthusiast for the Open University, and I think the Open University also gave Ian a lot. It gave him a lot of opportunity to make it in his own way, what he wanted, and what he believed in. And he very much believed that there was no elitism in geology. Anybody, anybody, could do useful geology, and I think that still goes on, people still believe it. He didn't consider you had to be an expert in geology to enjoy it or make useful contributions. So well done to Jane Randle. I look forward very much to seeing that autobiography.

This morning, Anne O'Connor did a brilliant job of talking while we were sitting outside the lecture theatre — and made the point about how difficult it was to sort out the Ice Age, even to decide if there were an Ice Age, and sort out the glacials and interglacials; and to connect it to the animals within them. And again that's part of the history of geology, sorting out what's going on in the Ice Age.

And then later we had Chris Duffin who was talking about Louis Agassiz, who I think is a candidate for the most colourful geologist. Louis was working on the Alps, also sorting out the Ice Age, in one of the few places where the UK hasn't led the development of geology.

John Mather made the really useful point about the practical drivers of geology. London needed a water supply —and you really need to understand hydrogeology to know how the best way to supply that water. So the engineering side was necessary to understand what was going on. And I'd like to comment that I wish we could have learned more from the 19th-century plague and understood it; we'd have gone a bit faster with the water supply.

Richard Howarth's idea on data presentation made me think how we take computers for granted. Here we're running Powerpoints, and we can do incredible things with graphs. I don't draw graphs any more, I just press a button on a computer; if the data's there it just does one for me. And then I look at the graph and think that's stupid, and start adjusting it, but that's what we do. But we know that those are good ways to show data and to convince people of things. And perhaps the history of understanding is connected into its data presentation.

Barry Thomas's talk was about the history of geoconservation. I said yesterday at the book launch for Cynthia's book that geoconservation is possibly the newest branch of geology. And it's something that's really worth looking into as it's extremely important and it is beginning to be recognised as such.

Tom Sharpe's very entertaining talk on de la Beche was fascinating — I think de la Beche is the other candidate for most colourful historical figure. The creation of the Geological Survey to pay for his mapping was brilliant; connected into the military need for geological surveying. That was somebody who needed a job where the military needed something doing, so it just fitted together. Scientific serendipity worked very well.

Patrick Wyse Jackson — geochronology is something that has always been the real clue to understanding the Earth. Herodotus; when I was doing my thesis research I worked a lot on the eastern Mediterranean — when I say on the eastern Mediterranean, I mean literally on it because I'm a marine geophysicist — and I discovered a seamount; and I was very proud of my first discovery of a seamount. There's a tradition that if you discover a seamount you can name it after somebody, but you can't name it after yourself, so I did know a little but about Herodotus and because I was in the eastern Mediterranean I gave Herodotus a seamount, and you'll see it on maps. He was one of the people that Patrick mentioned as being very much into thinking about the age of the Earth from sedimentation.

Arthur Holmes, I think there was the person who kick-started the real development of understanding the age of the Earth with his radioactive data; and we've still got that today. I'm surrounded by labs in my department, most with mass-spectrometers, all seeming to be using various methods of radioactive dating. Those who came to the AGM in April would have heard a talk by Simon Kelley on radioactive dating using the Potassium/Argon method.

But meteorites were the real clue to the age of the Earth. And after all of that the astronomers had to sort out the age of the universe.

Coming out of all of this is all of us and the Open University Geological Society. We are also the history of geology. We are where it's going, now. We can really influence what goes on. I said to you that geoconservation was one of the things that's going to be the new branch of geology. We're so well placed, from our local branches and local contacts, to work in with that. So I commend that to you.

And I just want to say thank you very much to the organisers for an absolutely fantastic symposium. My congratulations to all.

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